

*FY01 Dept. Review*

*Computational Physics  
&  
Simulation Frameworks (9232)*

*May 30, 2001*



Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.



# We have a lot to cover.



- Introductions
  - New Staff
- Overview
  - Scope/Highlights
  - Funding
- Particulars
  - Greg Bessette
  - Archie Farnsworth
  - Paul Demmie
  - Paul Taylor
  - Ray Bell
  - Dave Crawford
  - Stewart Silling
  - Marlin Kipp
  - Rebecca Brannon

# First, meet the new staff.

## Greg Bessette



- BS ME – University of Florida,  
MS Eng. Mechanics – University of Florida  
PhD Eng. Mechanics – UT Austin
- 8 years @ Eglin AFB (concrete penetration, explosive cratering, structural response to blast loading)
- Current work assignment: NMD, Zapotec

## Jill Rivera



- BS ME - U. of Kansas,  
MS ME - UNM
- 11 years @ SNL (SW development: solid model interrogation for manufacturing, NG tube expert system, stockpile tester design and deployment)
- Current work assignment: W76 Radar Tools, W76 AF&F Cable Tools

# Next we have an ...

- Introductions

- New Staff



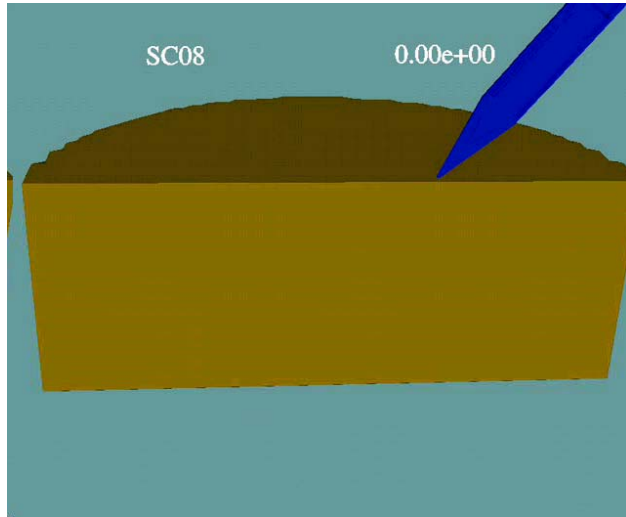
- Overview

- Scope/Highlights
- Funding

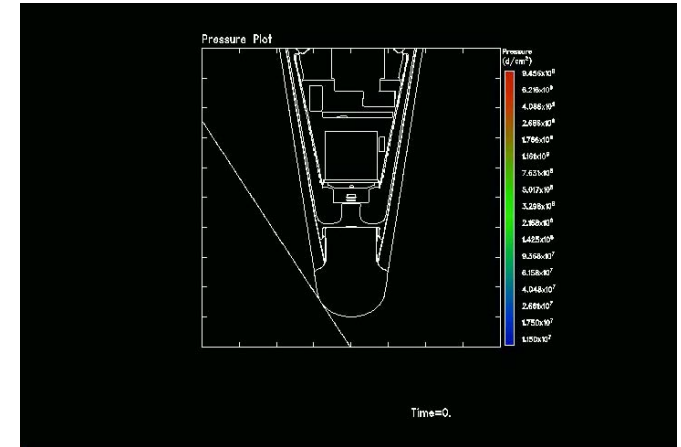
- Particulars

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# We historically do...



dynamic

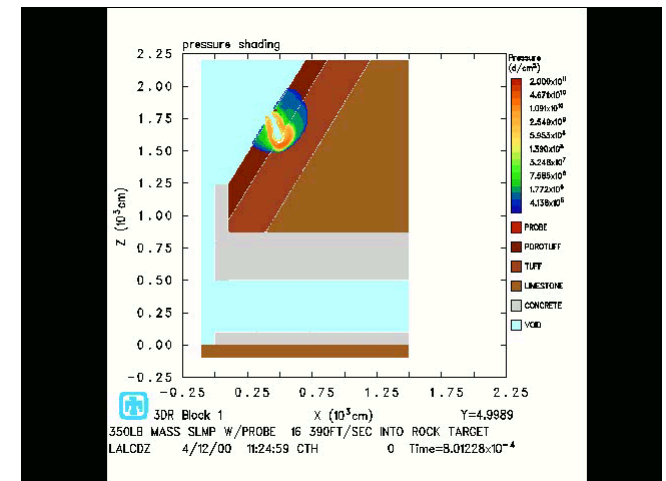
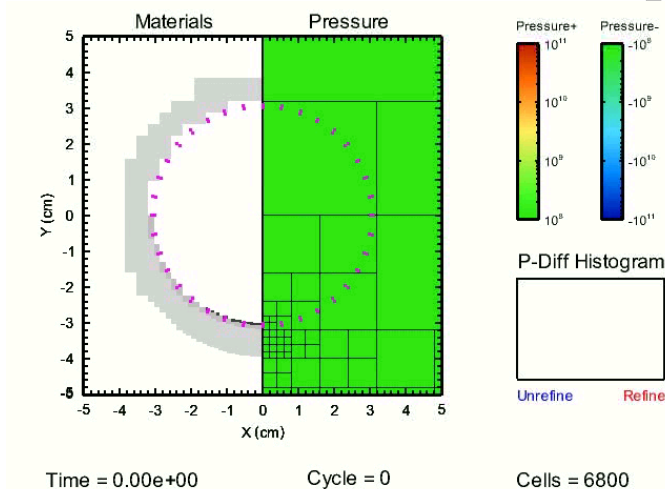


# SHOCK PHYSICS

large deformation

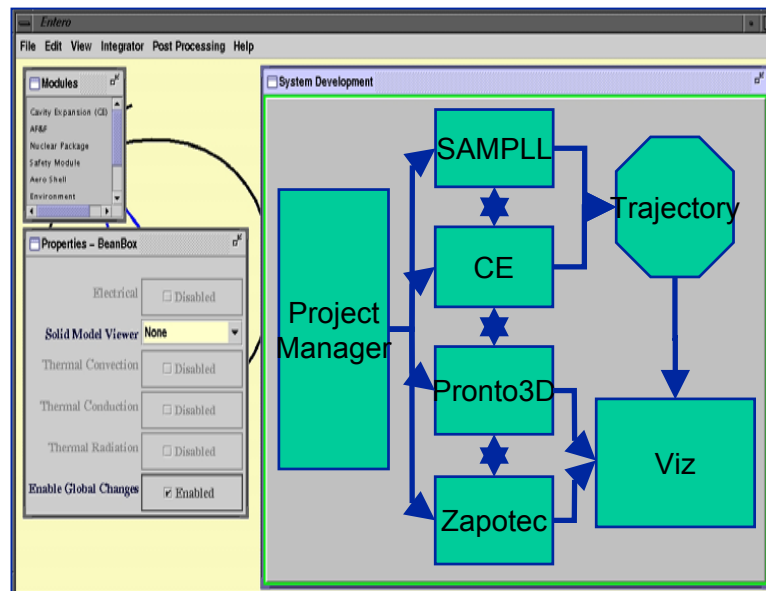
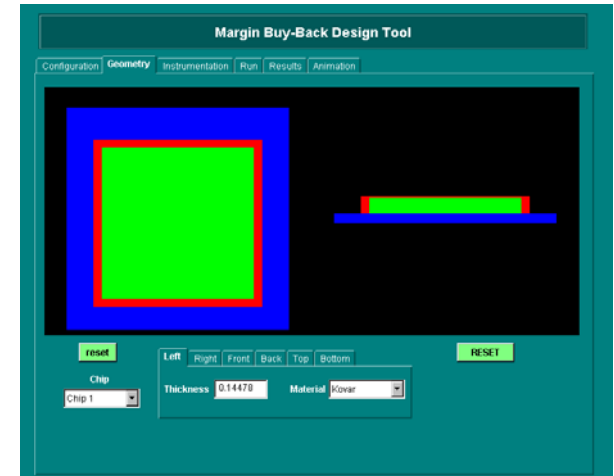
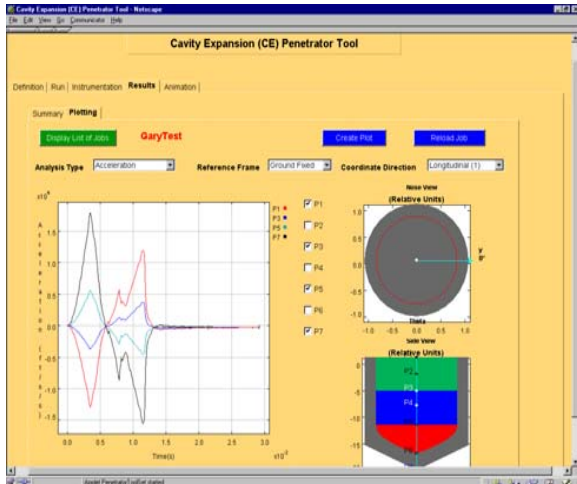
high strain-rate

materials



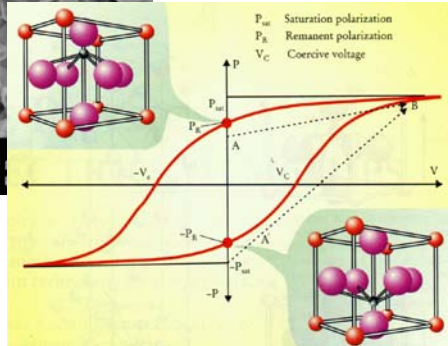
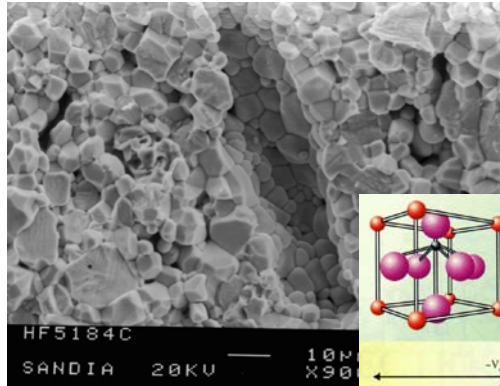
and we do ...

# M&S Tools and Frameworks





# In this context, we research...

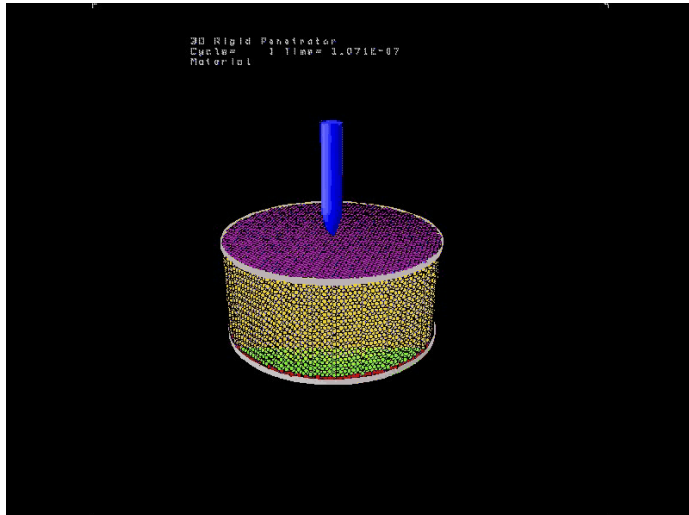


## Material Models

- brittle
- porous
- multi-constituents
- multi-phase
- damage
- macrostructure
- microstructure



Rebecca



## Peridynamic Theory

- same integral equations apply everywhere
- even in discontinuities, like cracks
- lends itself to mesh free methods

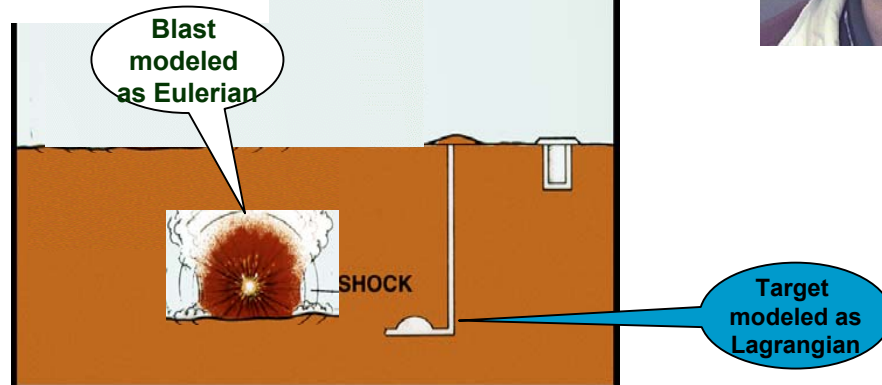
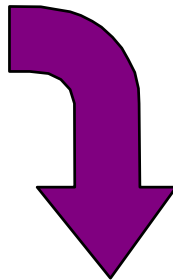
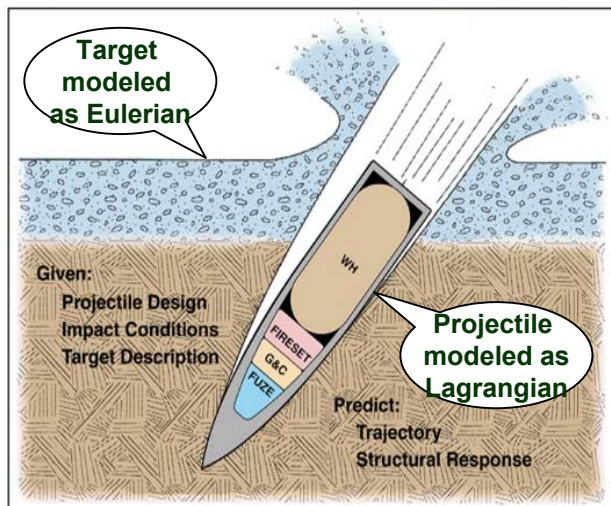


Stewart

# We develop ...

## Earth Penetrator Technologies

- “holy grail” of shock physics
- coupled codes (splat/bang & rattle)
- many variants



Ray



Greg



Archie

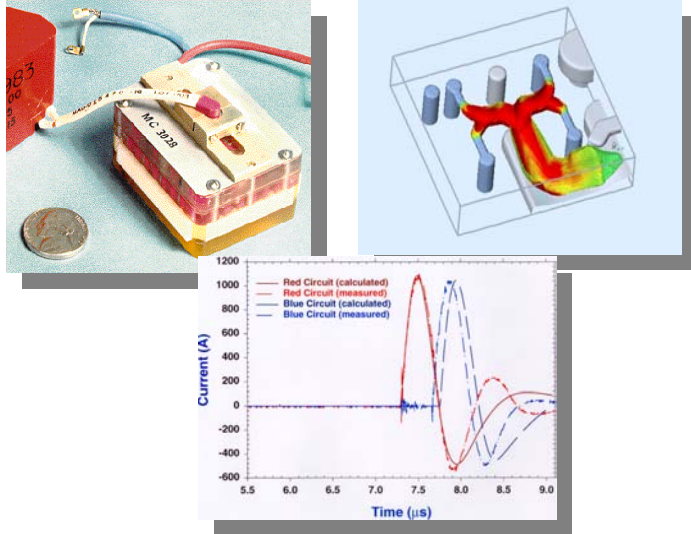


Dave





# We apply ...

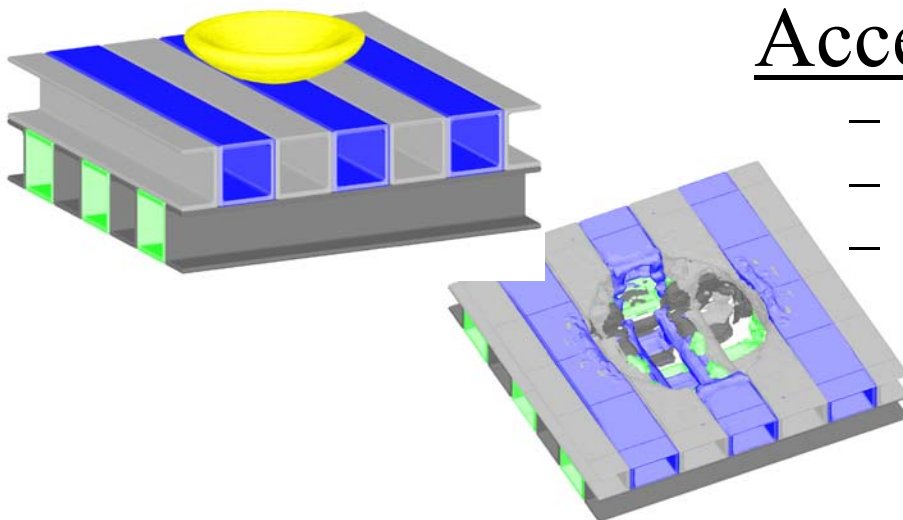


## Firing Set

- electromech. model
- model explosives, pzt
- aged materials



Paul



## Access Denial

- terrorist attack
- delay access
- impact design

Marlin



Jason

# We support ...



Paul



Bob

## Production CTH

- Interface with user community (> 260 licenses, 1000 users)
- Conduct user training classes
- Code debugging
- Configuration management
- Large and growing number of operating system
- Major releases, code updates
- Documentation
- Telephone support



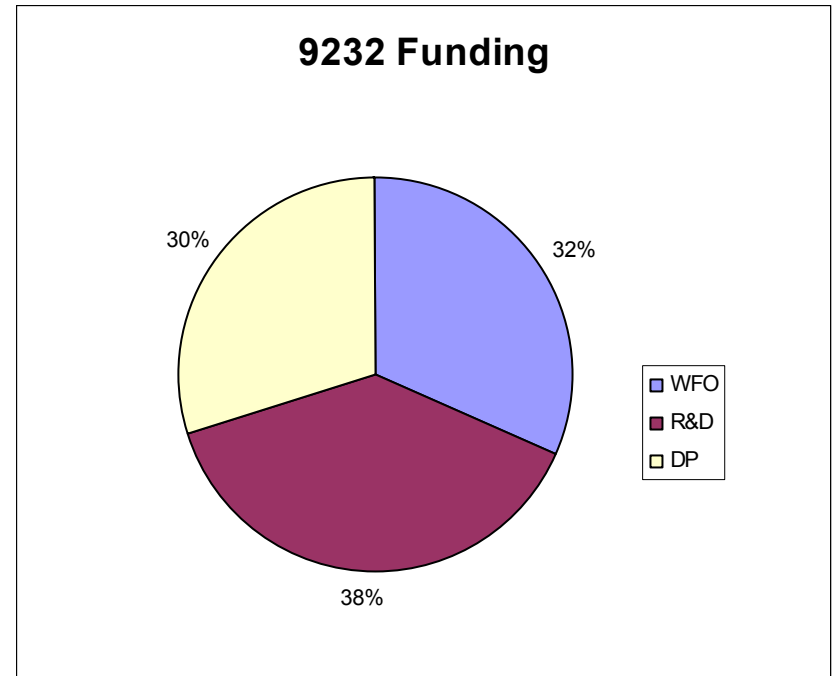
Millie



Marilyn

# Our funding...

- is based on ~25 related projects
- amounts to >\$3 million, plus additional walk-in work
- is balanced across
  - Research (R&D/DP)
  - Development (R&D/DP/WFO)
  - Application (DP/WFO)
  - Support (DP/WFO)
- supports collaborative work, primarily with 9231
- comes from internal and external sources



# And now for the meat!

- Introductions

- New Staff

- Overview

- Scope/Highlights
- Funding



- Particulars

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# FY01 Department 9232 Review

Greg Bessette



May 30, 2001



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# FY01 Projects

- ZAPOTEC
- Corporate Lethality Program (CLP)

# ZAPOTEC: Overview

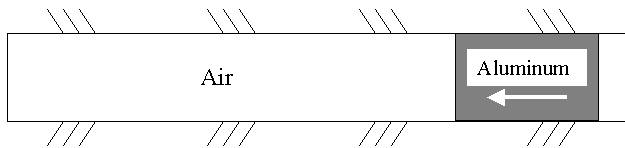
- Development of a coupled Euler-Lagrange capability
  - Directly couple CTH and PRONTO3D codes
- Coupled approach allows solution of a broader range of problems

# ZAPOTEC: On-Going Efforts

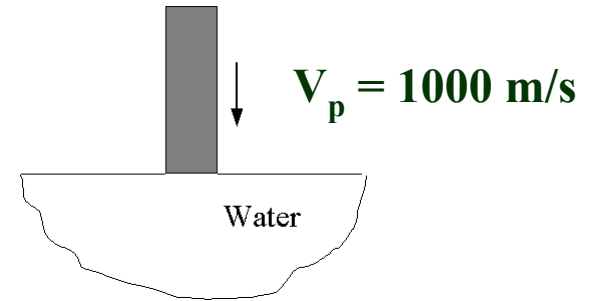
- Software Development
  - Developed more user-friendly command file
  - Consolidation of code for CVS implementation
- Validation and Documentation
  - Pull together suite of example problems
  - Develop accompanying documentation
  - Should provide guidance for performing ZAPOTEC analysis

# ZAPOTEC: Example Problems

## Gas Piston

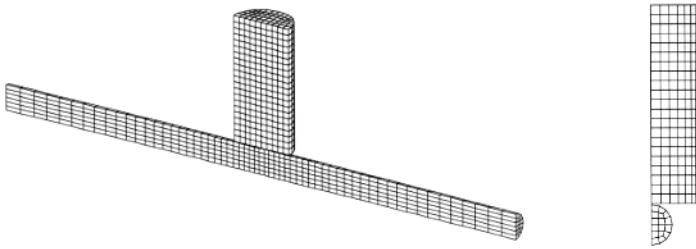


## Tungsten Rod Impacting Water



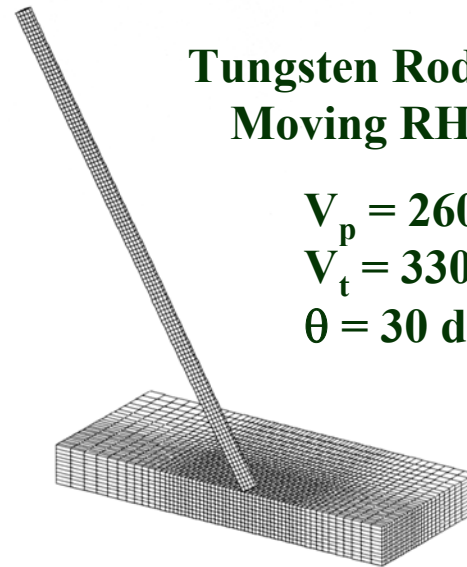
## Aluminum Cylinder Impacting Tungsten Rod

$$V_p = 144 \text{ m/s}$$



## Tungsten Rod Impacting Moving RHA Target

$$\begin{aligned} V_p &= 2600 \text{ m/s} \\ V_t &= 330 \text{ m/s} \\ \theta &= 30 \text{ deg} \end{aligned}$$



# ZAPOTEC: Future Efforts

- Consider additional example problems
  - Earth Penetrating Weapons
  - Anti-armor Applications
  - Air Blast Loading on Concrete Structures
  - Soil-Structure Interaction
- Software Development
  - Add support for additional PRONTO element types

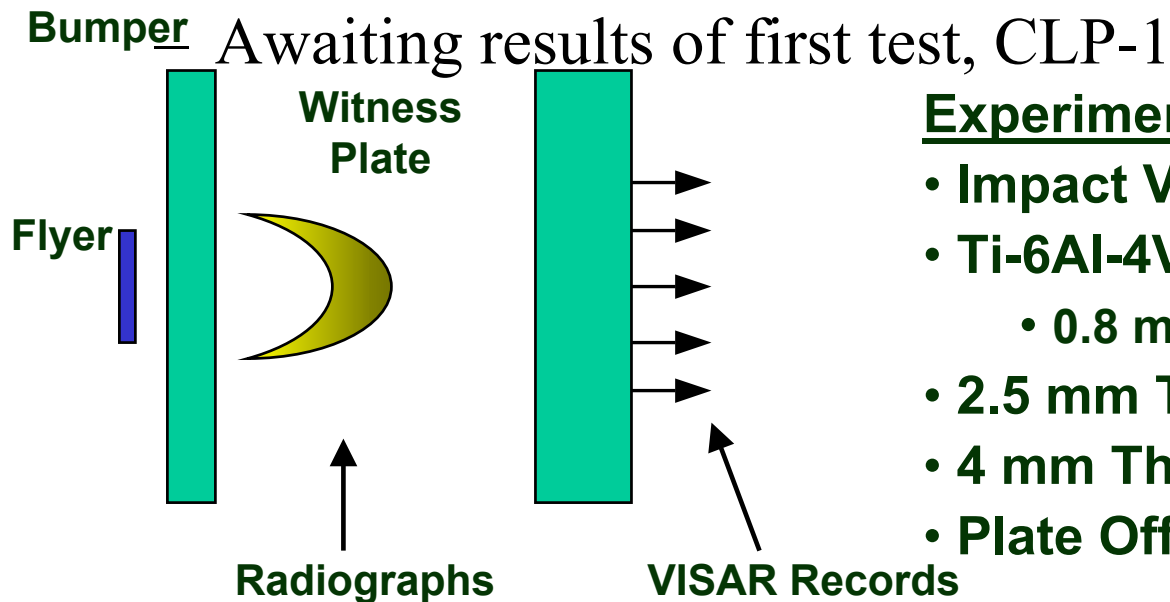


# Corporate Lethality Program: Overview

- Tri-Lab code validation effort for hypervelocity impact applications
- Supports National Missile Defense initiative
- Considers wide range of engagement scenarios
  - Variations in impactor and target configurations
  - Both 2D and 3D code validation

# Corporate Lethality Program : On-Going Efforts

- Program is just beginning
- Currently focused on modeling simplified 2D configuration
  - Pre-test calculations completed using CTH



## Experimental Configuration:

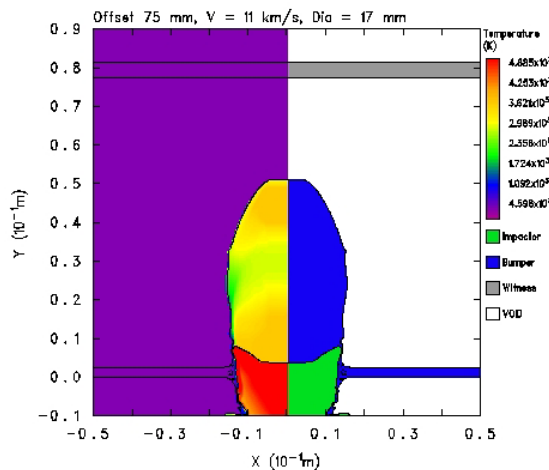
- Impact Velocities: 6 and 11 km/s
- Ti-6Al-4V Flyer Plate
  - 0.8 mm Thick x 17 mm Diameter
- 2.5 mm Thick Al Bumper Plate
- 4 mm Thick Al Witness Plate
- Plate Offsets: 75, 100, 150 mm

# Corporate Lethality Program: Temperature and Material Plots

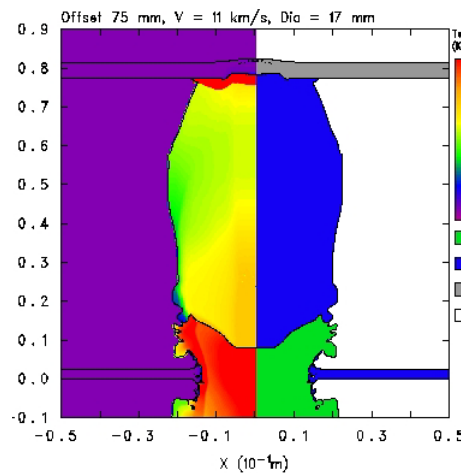
**Impact Velocity: 11 km/s**

**Flyer Diameter: 17 mm**

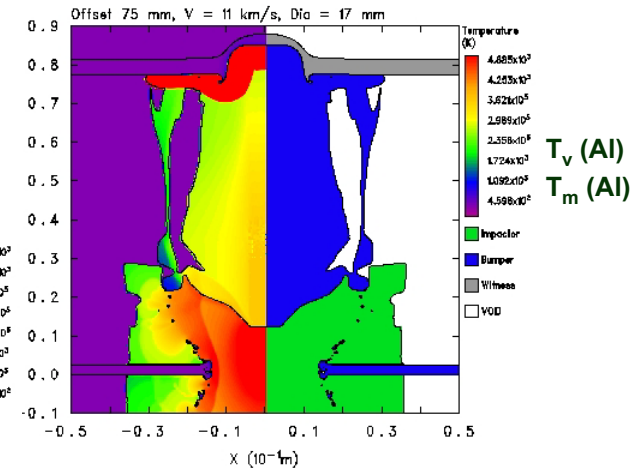
**Plate Offset: 75 mm**



**t = 4 μs**



**t = 8 μs**



**t = 12 μs**

**For Reference:**

**T<sub>m</sub> (Al): 933 K**

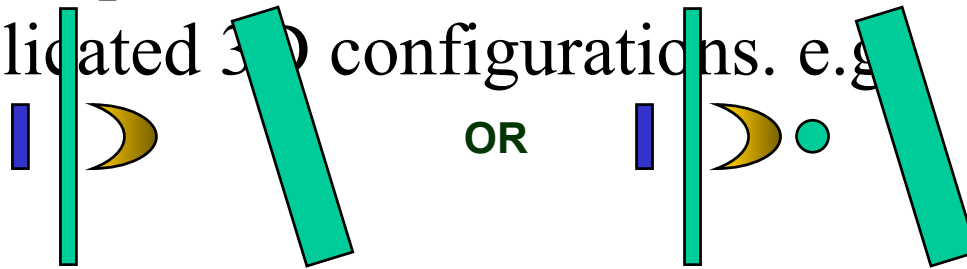
**T<sub>v</sub> (Al): 2330 K**

**T<sub>m</sub> (Ti): 2075 K**

**T<sub>v</sub> (Ti): >3075 K**

# Corporate Lethality Program: Future Efforts

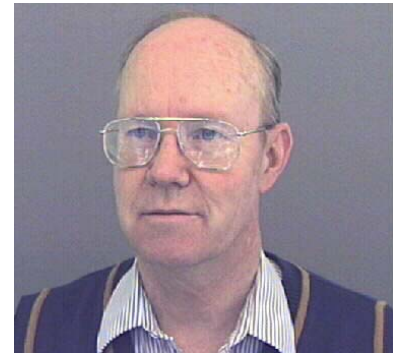
- Near term
  - Model experiment CLP-1
  - Requires full 3D calculation
- Long term
  - Perform pre-test calculations for more complicated 3D configurations. e.g.





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Archie Farnsworth



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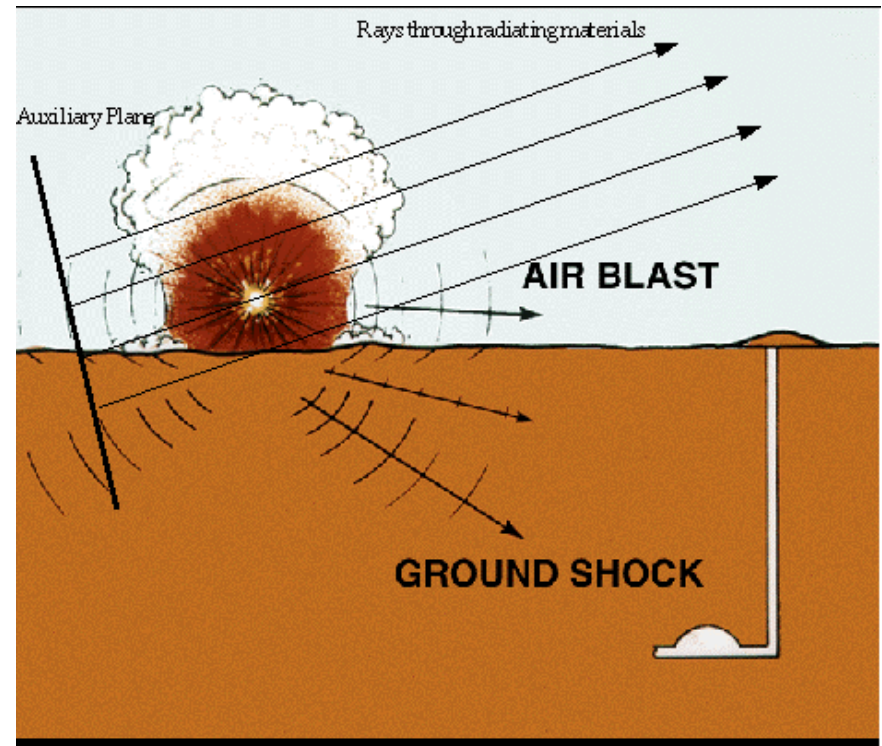


# FY01 Projects

- Optical Signal Post Processor for ALEGRA for 5700 and 6500
- Laser Driven Flyer Plates for EOS Studies (especially for thin structures) LDRD
- Navy Kill Vehicle Lethality Study for Specified RV's for 15400 and Navy
- Smaller projects: (1) CTH energy balance routines, (2) NUDET in cavern, (3) Lethality of X-ray flux on RV

# Detection and Location of Nuclear Detonations: A Sandia Mission

- Current sensors, algorithms: air burst data, old designs
- Target set now includes hard deeply buried targets requiring ground bursts, for which there is no data
- Modern weapon designs produce different signals
- New **data** is unlikely, so ... **computation** must suffice!



# Physics of Optical Signals from NUDETs

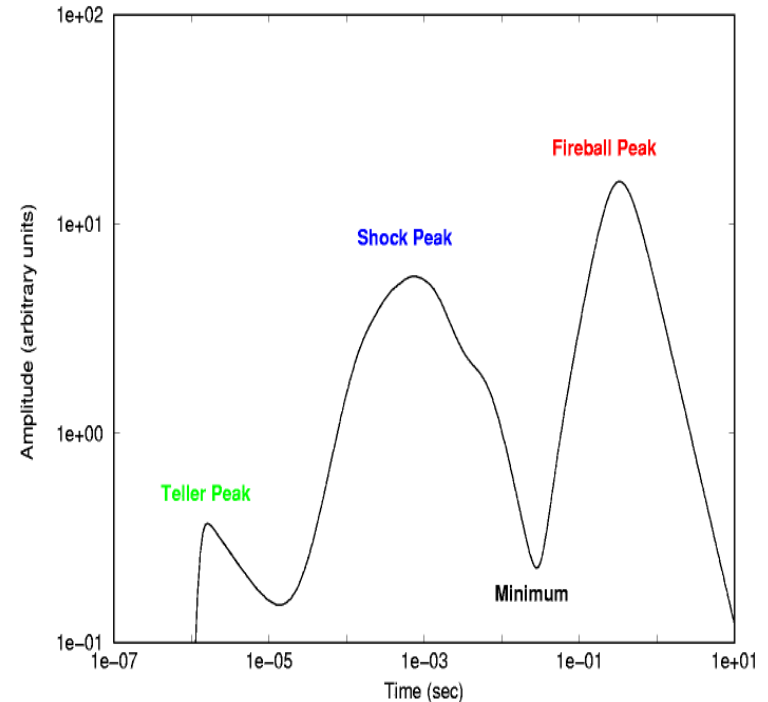
- Three pulse signal from NUDET:

**Teller light** - air fluorescence  
(Gamma rays, Neutrons)

**Shock light** - shock wave in air

**Fireball light** - prev. heated air

- Trigger on rise of shock peak:  
most complex, uncertain part



# The Optical Signal Post Processor

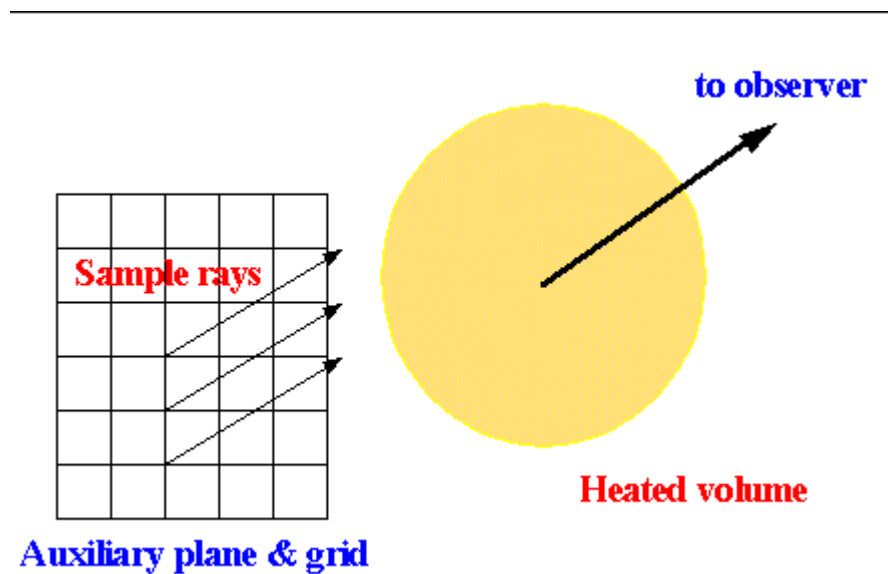
- Required Input:

- Direction to observer
- ALEGRA data
- Air optical opacities

- The Post Processor:

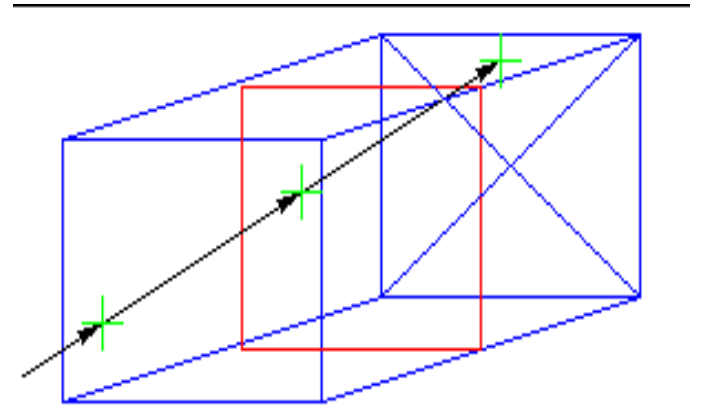
- Define sampling rays
- Sample data along rays
- Compute radiative intensity
- Sum contributions to signal

- Output: Data to compute quantitative sensor response



# Computation of Radiative Intensity

- Path through arbitrarily connected cells of ALEGRA grid:  
Find intersections with face  
Save distance through cell
- Computation of Ray Intensity on emergence from grid:  
Solve Eq. Of Rad. Transfer through succeeding cells



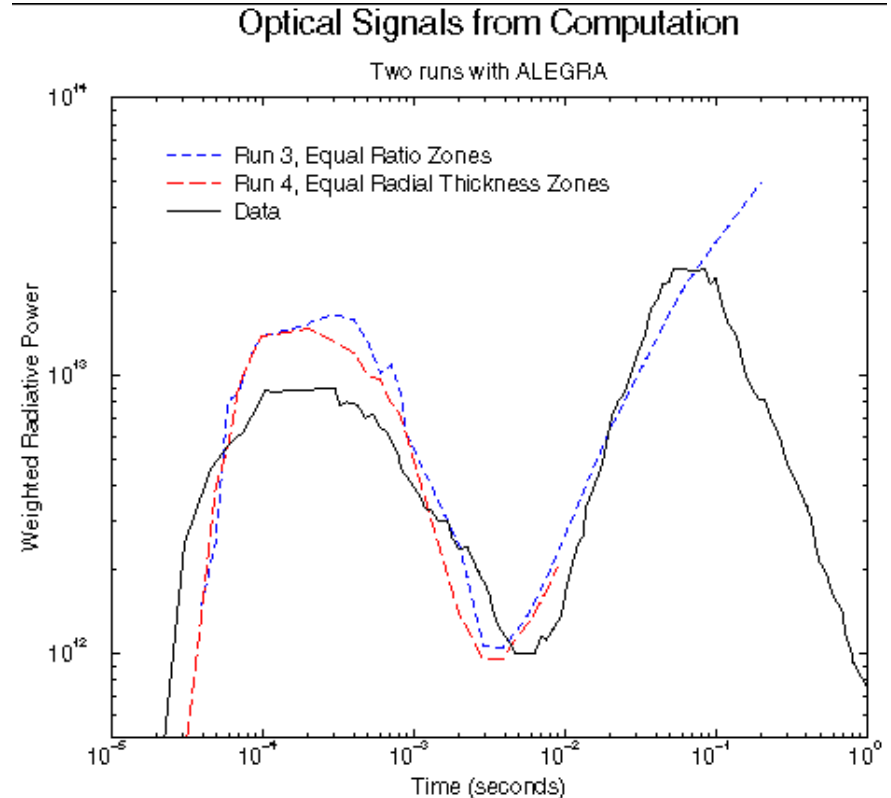
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$$\frac{1}{c} \frac{\partial I_\nu}{\partial t} + \frac{\partial I_\nu}{\partial s} = \rho \kappa_\nu (E_\nu - I_\nu) \text{ through cell: } I_\nu = I_\nu(0)e^{-\tau} + E_\nu(1 - e^{-\tau})$$

where  $\tau_\nu = \int \rho \kappa_\nu ds = \rho \kappa_\nu \Delta s$  through a cell

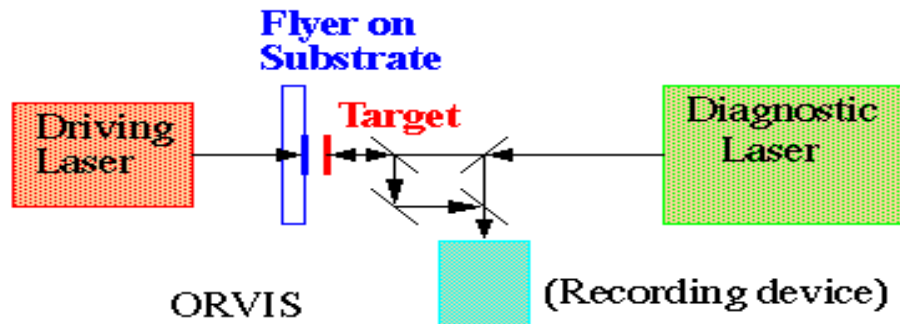
# Post Processor Present Status

- Main features reproduced but lacking detail
- Timing of minimum indicates yield
- Physics Still Needed:  
Preconditioned Air  
Radiative Losses at  
long wavelength



# Laser Driven Flyer Plates for EOS Studies

- Needs: Methods to examine “thin” materials  
Less costly methods for any material
- SNL Assets: High power lasers to drive flyer  
Excellent measurement tool (ORVIS)  
Developed computational tool (CTH)

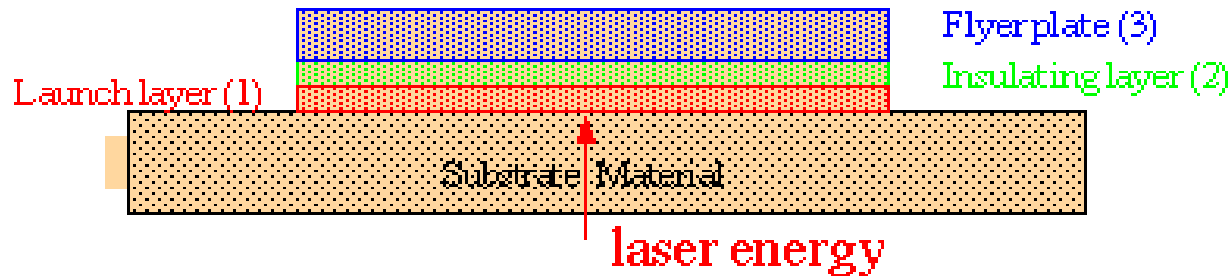


# Computational Capability

- CTH modifications allow laser energy deposition for normally incident rays, following the CTH grid
- Energy Deposition algorithms for laser absorption in the metallic or plasma state

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Typ



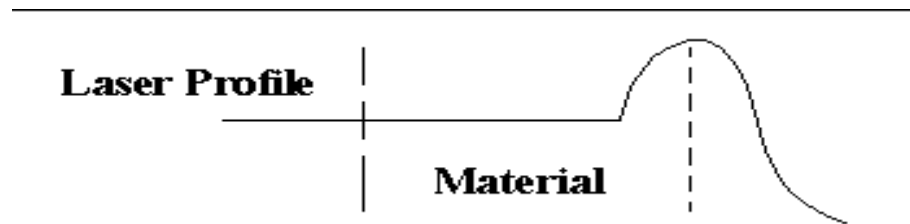


# 1-D Variations of flyer assembly

- Varying launch layer 1, constant sum of layers (1) + (2)  
Chose value of .25 microns (0.1 - 5.0 range)
- Fixed launch layer 1, varying layer 2 thickness
- Varying layer 2 thickness, at greatly reduced thermal conductivity
- Results: Very large insulating layer to cool back side  
All cases show cool front (impact) side

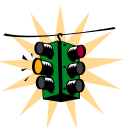
# Variations in 2-D

- Laser deposition profile variations:  
Flat center, Gaussian roll off at edge  
Flat center, high ridge at edge, then roll off



- Result: Large variations in deposition profile produce barely noticeable effect in foil flatness

Suggests little sensitivity to details of profile





# FY01 Department 9232 Review

Paul Demmie



May 30, 2001

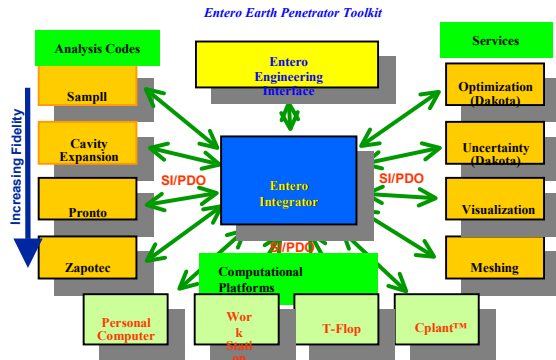


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# FY01 Projects

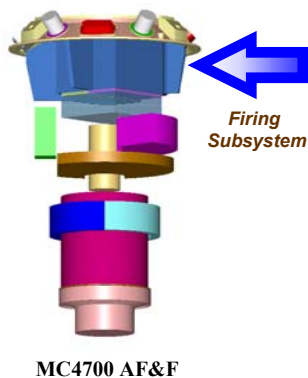
- The Entero Earth Penetrator Toolkit
  - Funded by CSRF



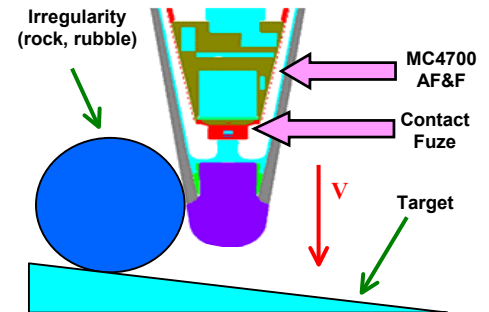
- The MC3028 Firing Set for the W76/Mk4 and W78/Mk12A
  - Funded by ESP



- The MC4700 Replacement AF&F for the W76-1/Mk4A
  - Funded by DP



- The W76-1/Mk4A: Collisions with Obstacles and Impacts with Irregular Targets
  - Funded by ASCI



# Goal of the ENTERO Project

*To develop a flexible environment for the design and analysis of complex systems in*



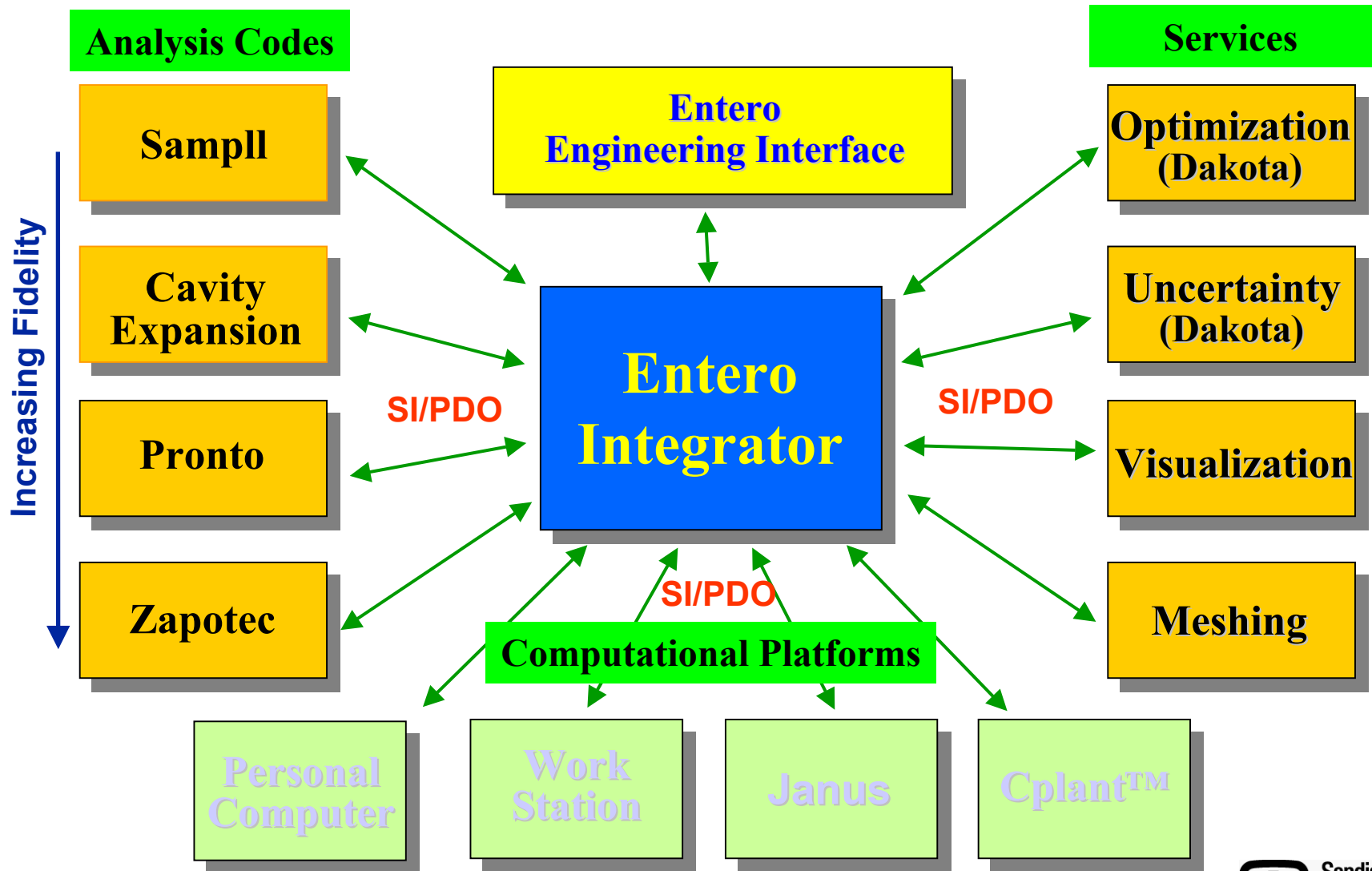
*diverse environments from a system-oriented, module-oriented point of view using models with varying degrees of fidelity*



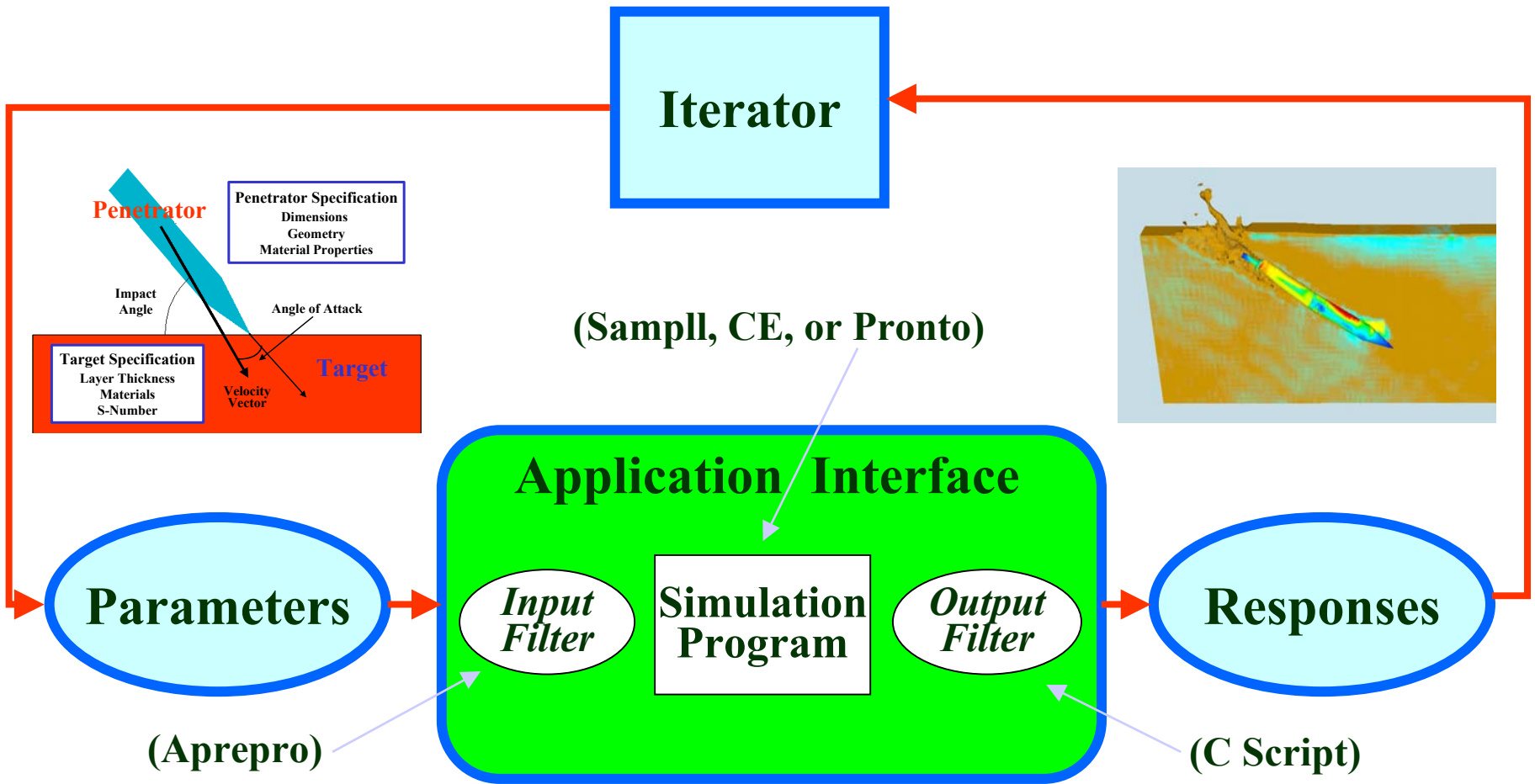
*and accessed by means of a web-like user interface.*

# The Entero

## Earth Penetrator Toolkit (EPT)



# Optimization and Uncertainty in the Entero EPT Using DAKOTA

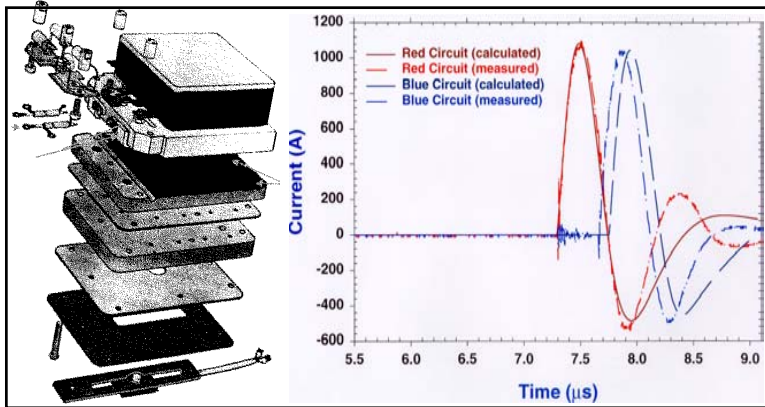


# Accomplishments for the Entero EPT

- Completed a top-level design of the Entero EPT
  - Summarizes vision of the mature toolkit
- Developed a prototype for critique by targeted users
  - Team effort with Joe Castro, Luis Hernandez, Dave Miller
- Developed methodology for integration of penetrator analysis codes with DAKOTA
- Modified Sampl1 code for integration in the EPT
  - Includes damage criterion used by designers
- Illustrated methodology with example problems
  - Summarized in paper *Optimal Design of Complex Systems Using the Entero Code System*



# Modeling the MC3028 Firing Set and Simulating Its Performance



## Goal

- Create a comprehensive, coupled 3-D electromechanical (EM), age aware model of the MC3028 slim-loop ferroelectric (SFE) firing set

## Approach

- Use EMMA, a 3-D Lagrangian-Eulerian computer code which includes electromagnetic field calculations and attached circuits
- Create computational model
- Simulate performance

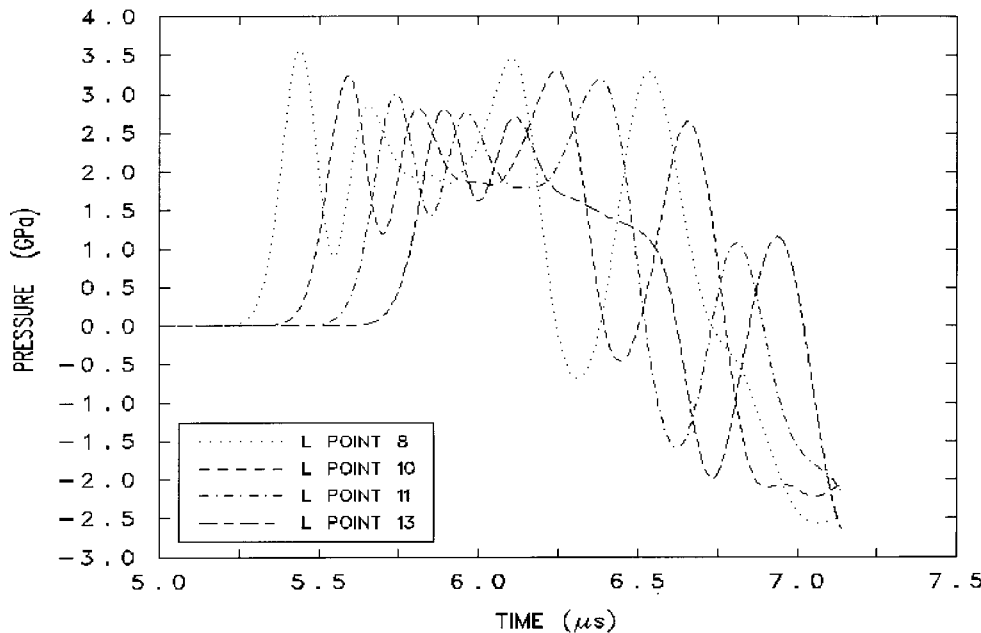
## Customer/User

- **George Clark**

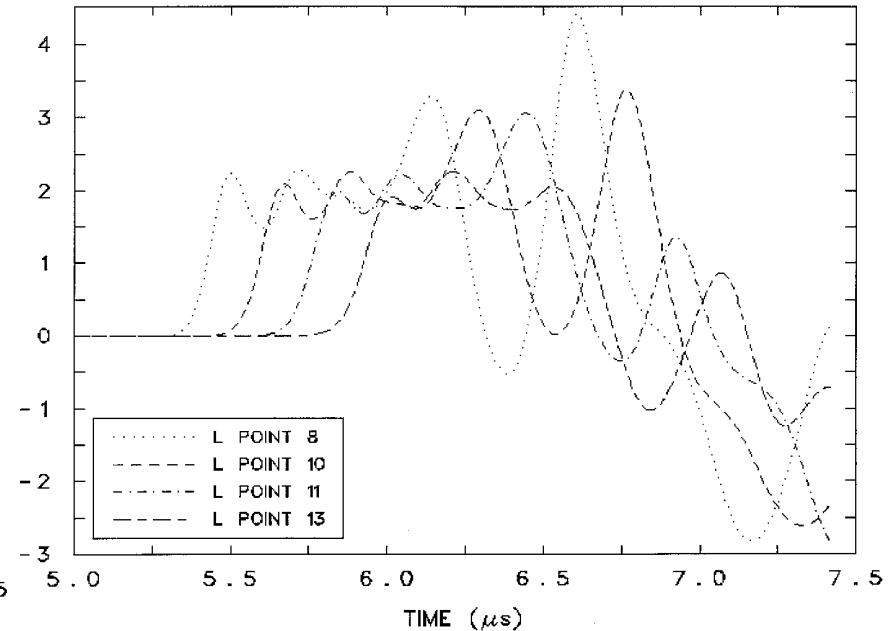
## Accomplishments

- **Met all customer expectations by end of FY00 including documentation**
- **Obtained new SFE data (Pandora's Box)**
  - PBZT conductive at high pressures, fields
- **Added mylar layer and interfaces between SFE elements to calculate correct pressures in SFE stack (full-stack and quarter-cell models)**
  - Possible because of Cubit development and teaming
- **Developed new EM model for SFE material**
  - Includes strain and electric field dependence
- **Obtained new data for validation process**
  - Preliminary comparisons look good

# Comparison of Pressures in SFE Stack



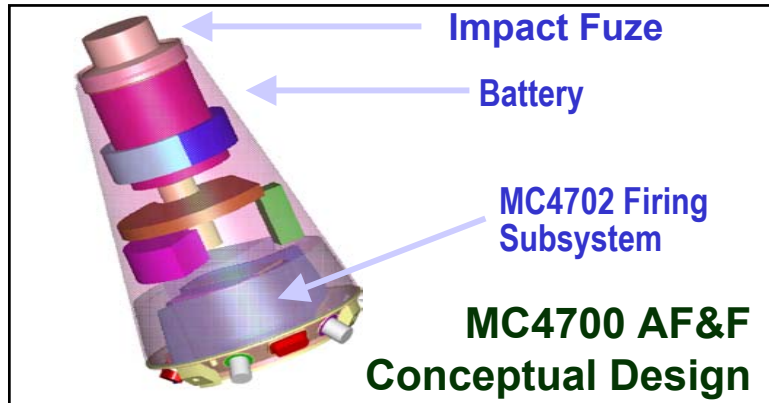
Best Estimate Simulation **without**  
Mylar and Interfaces



Best Estimate Simulation **with**  
Mylar and Interfaces

These results show effects on pressure of including a 3-mil mylar layer between buffer plate and SFE stack and RTV-foil interfaces.

# Analysis for Design of the MC4700 Replacement AF&F for the W76- 1/Mk4A



## Purpose

- Analyze impact of Mk4 reentry body (RB) into targets to predict impact-fuze performance
- Determine time MC4702 firing subsystem has to initiate detonators before some component critical to nuclear detonation becomes inoperable (timing requirement)

## Customer/User

- Randy Harrison

## Approach

- Create CTH model of W76-1/Mk4A
- Simulate impacts using CTH
- Determine timing requirement

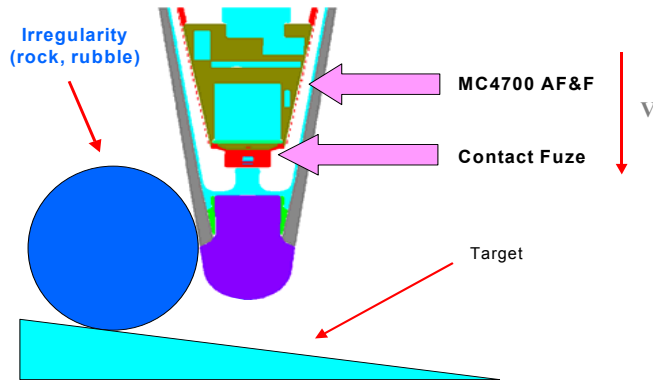
## Accomplishments

- Developed analytical method and criteria to assess damage to critical components (MC4702 and nuclear explosive package)
- Completed simulations into hard and soft targets for eight representative velocity-angle ( $V-\gamma$ ) points
- Determined that fuze operates at all  $V-\gamma$  points
- Determined timing requirement

## FY01 Milestones

- Develop a timing requirement (first quarter)
- Document in presentation (second quarter)
- Document in SAND report (fourth quarter)

# Collisions of the W76-1/Mk4A with Obstacles & Impacts with Irregular Targets



## Issues

- Simulations to support DSW customers have been performed with RB impacting a perfect target to develop a timing requirement for a firing subsystem
- DSW customer wants to know the effects of collisions with obstacles and impacts into irregular targets

## Customer/User

- Randy Harrison and Brad Godfrey

## Approach

- **Create CTH model of W76-1/Mk4A and template input for collisions and impacts**
- **Simulate collisions and impacts using CTH**
- **Analyze results and document**

## Accomplishments

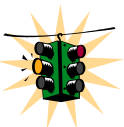
- **Summarized past hydrodynamic analyses**
- **Developed an initial target suite**
- **Created CTH models for simulations**
- **Completed base case simulation and one simulation of impact into irregular target**

## FY01 Milestones

- **Develop an initial target set (first quarter)**
- **Create CTH models (second quarter)**
- **Complete CTH simulations (third quarter)**
- **Document results (fourth quarter)**

# In Summary ...

- I have taken a proactive role in the Entero Project by developing an Earth Penetrator Toolkit emphasizing optimal design with uncertainty and
- I remained agile and responsive to the Defense Program's needs for Stockpile Stewardship on the W76 by
  - modeling and simulating the MC3028 firing set for ESP
  - performing analyses to develop a timing requirement for the firing subsystem in the W76-1 Replacement AF&F and
  - determining effects of obstacles and irregular targets on weapon performance.





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Paul A. Taylor



May 30, 2001



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# FY01 Projects

- CTH Development Project Leader
  - Contribute to CTH Development
- Constitutive Model Development
  - In support of:
    - Reactive Fragments Program
    - PBX Modeling (ASCI Program)
- Miscellaneous Tasks

# CTH Development Project Lead

- Mileposts
  - Distributed latest version (FEB01) of CTH to external customers with:
    - Adaptive Mesh Refinement (AMR)
    - Spymaster Graphics (must be used for 3D AMR)
    - New EOS, Strength, & Damage Models
    - New/Updated Features
      - Boundary Conditions
      - Convection Options
    - Limited Distribution (NT version) via FTP & Encryption
  - User Support & Training
  - New User Licenses Issued



# FEB01 CTH: EOS Models

- Baer Viscoelastic Model
  - describes time-dependent hydrostatic response according to a Maxwell viscoelastic model
  - examples: PMMA, Kel-F
- Grady P- <sup>$\lambda$</sup>  Geological Mixture Model
  - describes nonequilibrium compaction of a mixture of geological materials
- Time-Dependent JWL Model
  - modification of conventional JWL EOS to include delayed energy release
  - example: Aluminized Explosives

# FEB01 CTH:

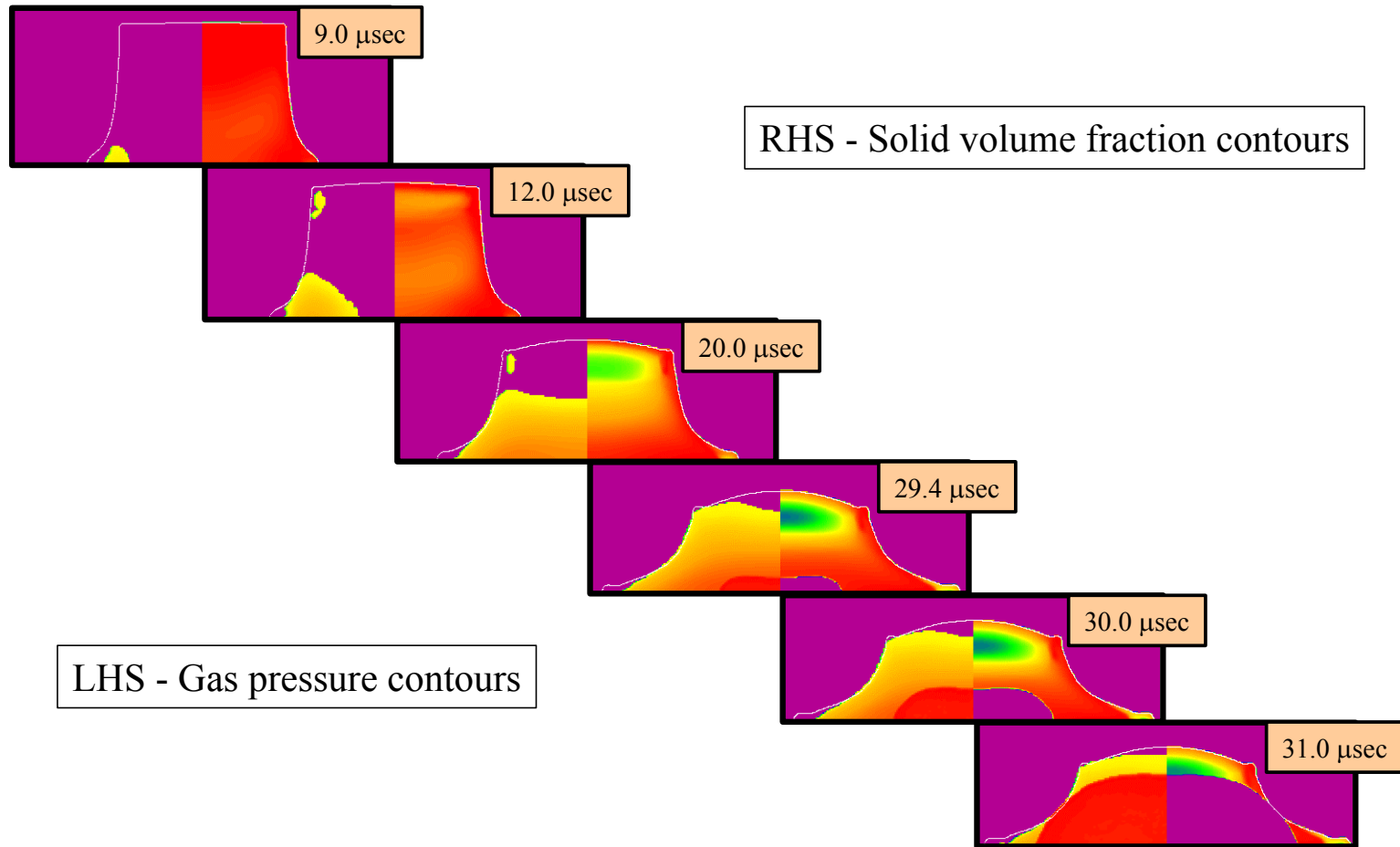
## EOS Database Improvements

- New EOS Sesame Tables
  - Plastics:
    - Teflon, PMMA
  - Carbon
- Improved/Corrected Material Parameters
  - Arrhenius Reactive Burn (ARB) Model:
    - Teflon, PMMA, Graphite Epoxy, Quartz Phenolic
  - Phase Transition (PTRAN) Model:
    - Iron (alpha, epsilon), Tin (I, III), & Titanium (alpha, omega)
  - Improved fits of MGRUN & HVRB Materials
- Available to CTH and ALEGRA

# FEB01 CTH: EOS/Strength/Damage Model

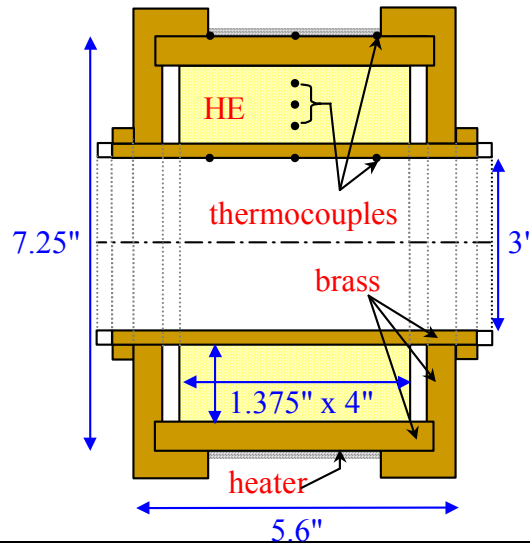
- CDAR (Coupled Damage And Reaction)
  - **Consists of 3 interacting modules (VEP, TDD, MP)**
- VEP (Viscous-Elastic-Plastic) Deviatoric Response
  - **Generalized Maxwell viscoelastic model**
  - **Strain-rate dependent plasticity**
  - **Response modified by damage from TDD module**
- TDD (Tensile Damage & Distention)
  - **Two damage processes: particle decohesion and binder scission**
  - **Describes viscoelastic-viscoplastic porosity evolution**
- MP (Multiphase) Burn
  - **Models energy release in porous energetic materials**
- **CDAR simulates SDT, DDT, and XDT behavior**

# CDAR Example: 2-D XDT Simulation

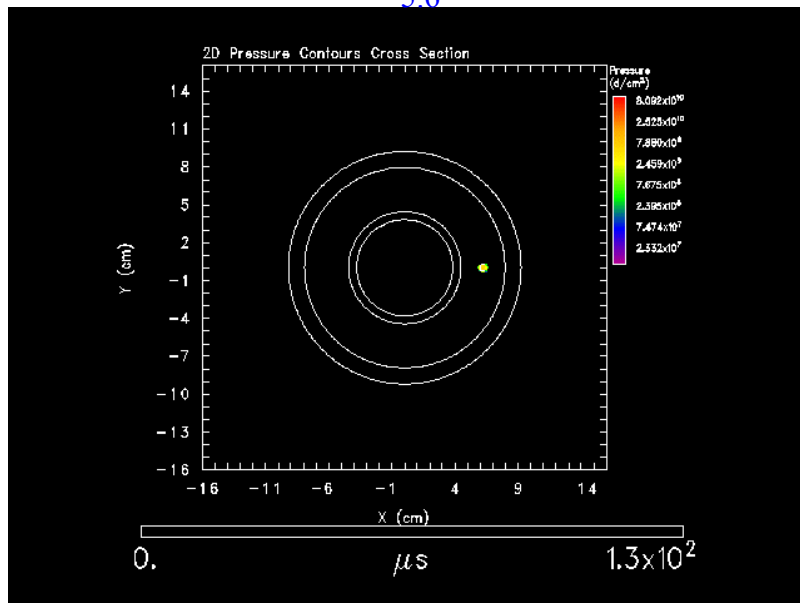


# CDAR Example:

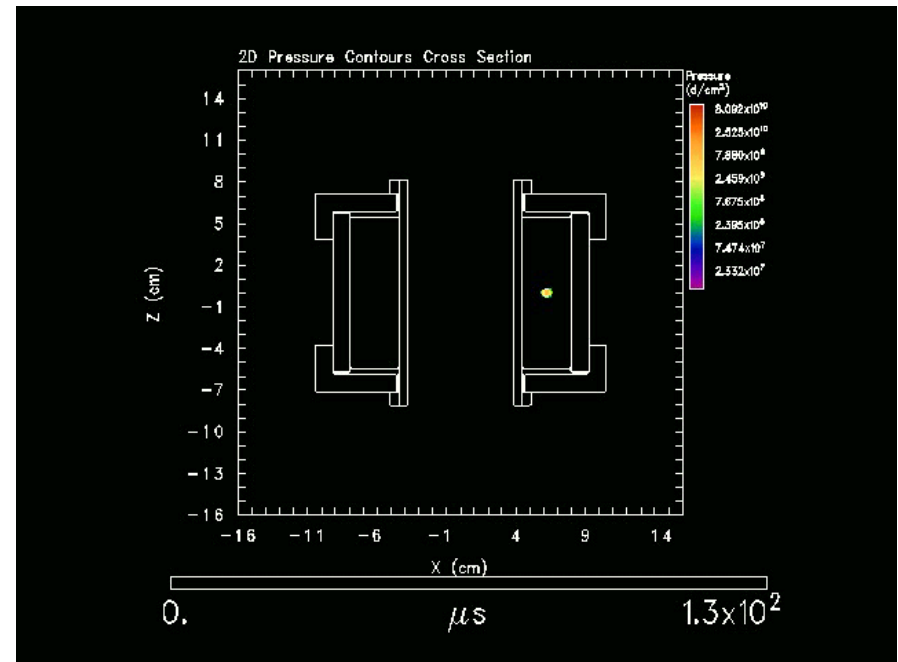
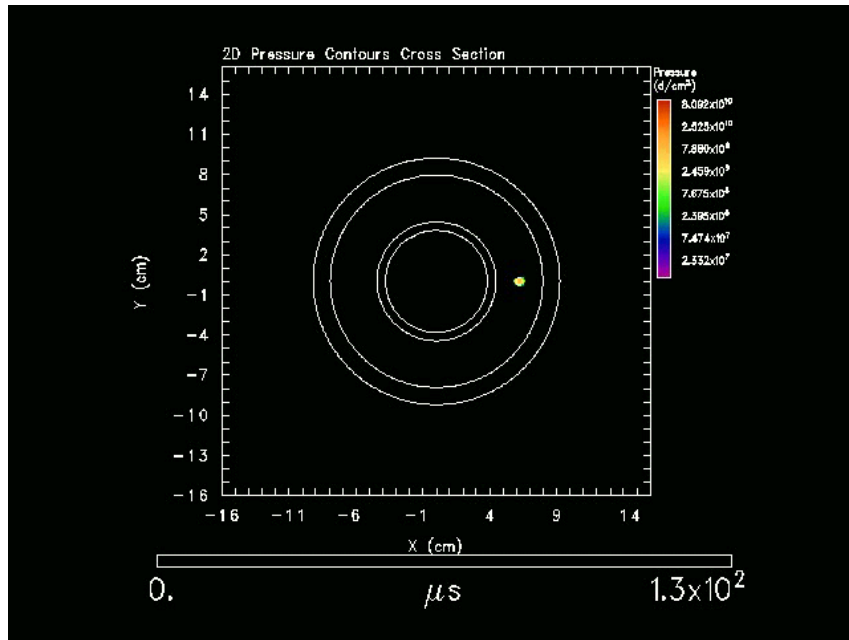
## HE Cook-off



- Simulation of cook-off experiment for PBX-9501 explosive (HE)
- Experimental configuration:
  - 2.5 Kg HE contained in brass cylinder annulus
- Test conditions:
  - Temperature increased to 150C for 2 hrs, to 180C for ~10 hrs
- Result: Violent Reaction



# HE Cook-off: THE MOVIES



# Distribution of FEB01 CTH

- Limited distribution of CTH for NT
  - Electronic Distribution
  - Runtime Security
- Encryption of CTH Executables, Documentation, and Data
  - Encrypted CTH distributed via FTP using Triple Data Encryption Standard (TDES)
- Runtime Security:
  - Ties execution of CTH to specific computer
  - No hardware lock (dongle) required

# User Support & Training

- Alpha version of FEB01 CTH
  - Released to DoD community in September, 2000
  - Bugs identified and fixed
- FEB01 CTH Distributed April, 2001
  - Offered CTH Basic User's Class March, 2001
    - 75% Class Attendees were DoD or DOE
  - Sponsored EOS Class w/J. Kerley March, 2001
- Respond to CTH user queries/problems via telephone & e-mail



# Constitutive Model Development

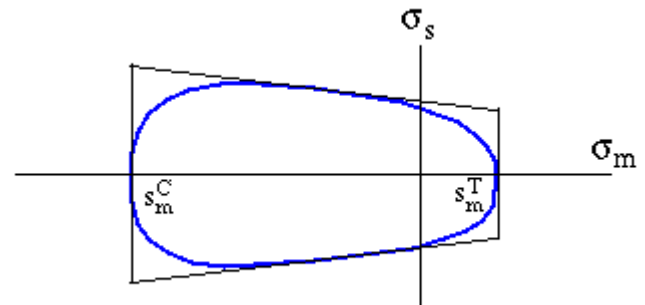
- In support of “Reactive Fragments” Program
  - WFO program with NSWC-DD
- Model constitutive behavior of Al/PTFE subjected to impact and penetration of Al & Steel targets
  - PTFE: Polytetrafluoroethylene (Teflon)
  - Al/PTFE exhibits mechanical loading induced reactivity  $\sim 20\%$  that of TNT detonation
  - Al/PTFE composition: 25% (wt.) Al in Teflon matrix

# Al/PTFE Mechanical Behavior Requirements

- Pressure Dependent Strength
  - Does pressure dependency exist?
  - Shear-induced dilatation?
  - If so, Triaxial Stress data required
    - Data collected at Sandia, NM; Geomechanics Dept.
- Gas Gun & ICE (Isentropic Compression) Data
  - Hugoniot & Spall
  - Wave Evolution Data
    - for Viscoelastic behavior
- Taylor Anvil Test
  - for validation of strength, fracture, & reaction representations

# Modifications to CDAR Modules for Representation of Al/PTFE

- Viscoelastic-Plastic Representation (VEP Module)
  - Define a Yield Surface
    - Pressure dependent
    - Different yield points in tension & compression
      - Separate plastic strain measures for tensile & compressive loading states
    - Shear induced dilatation
      - $\sigma_m$
      - »  $\sigma_s$  = **mean stress**
      - » = **von Mises stress**



# Modifications to CDAR Modules for Representation of Al/PTFE

- Damage Accumulation (TDD Module)
  - Mechanical Damage associated w/ shear-induced heating
  - Preliminary Damage modeling represented by simple “accumulated plastic strain to failure criterion”

$$D = \int \frac{\dot{\epsilon}_p}{\epsilon_p^f}$$

- Example:

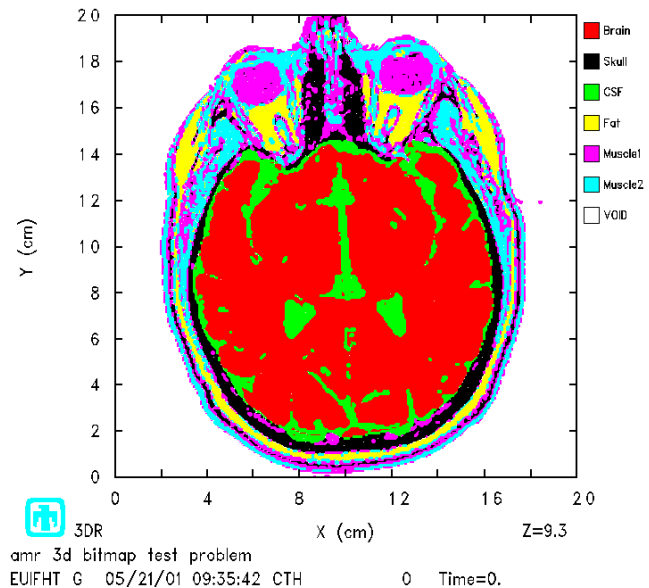
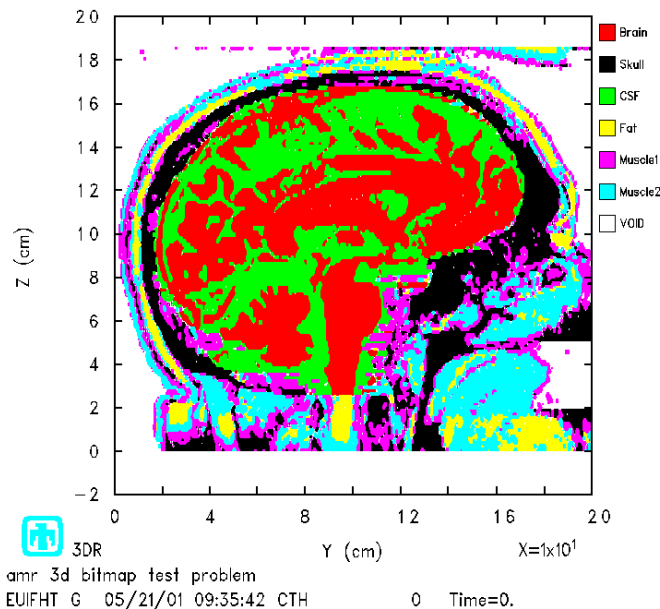
$$\epsilon_p^f = \epsilon_p^f(P, \sigma_{vm}, \dot{\epsilon}, T)$$

# Modifications to CDAR Modules for Representation of Al/PTFE

- Chemical Energy Release (MP Module)
  - Mechanical damage (adiabatic shear heating) causes decomposition of Teflon
    - Fluorine released, reacts with Al particles
    - Energy liberated
  - Work in progress in collaboration w/ 9116 staff on MP representation of Al/PTFE in CTH

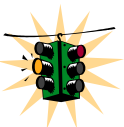
# Miscellaneous Tasks

- WFO Program
  - Conduct simulations of impact scenarios leading to Traumatic Brain Injury in humans
    - NM Telehealth Project (PI: Dale Alverson)



# Miscellaneous Tasks

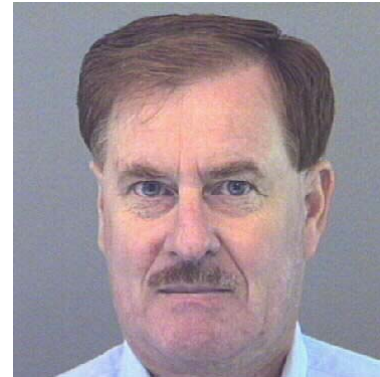
- Manage Consultant Contracts
  - Kerley Publishing: EOS consultation
  - Ben Cole: Consultant for CTH problems on Janus
- Commercial Licensing of CTH
  - Schlumberger Well Services
  - Prime Perforating Systems Limited





# FY01 Department 9232 Review

Ray Bell



May 30, 2001



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for the United States Department of Energy under contract DE-AC04-94AL85000.



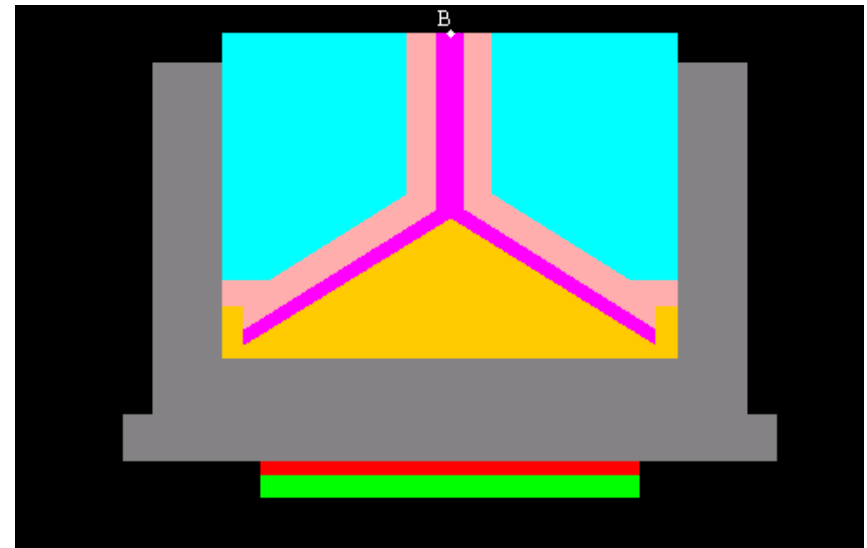


# FY01 Projects

- ISOLATOR Project (MC3347) for George Clark
- ZAPOTEC Coupled Code
- CTH

# Isolator (MC3347)

- **Develop an ALEGRA Model suitable to run EMMA to predict electrical output from the Isolator for SLEP.**
- **Started with existing Lagrangian model developed by Mark Boslough.**
- **Added PZT Disc, Lower Steel Disc, Brass Can, Explosive Detonator, and Epoxy Filler.**
- **Initial runs gave electrical output much lower than expected (pressure at the various surfaces matches experimental results)**



# Isolator (Cont'd)

- Iterated with Steve Montgomery on PZT parameters.
- Iterated further with Josh Robbins.
- Continuing to work thru ALEGRA issues.
- Latest model uses ALE Blocks for all Lexan parts to prevent mesh tangling at late times.
- Model now has 76 zones across the PZT and 4 zones across the Bond Layer.

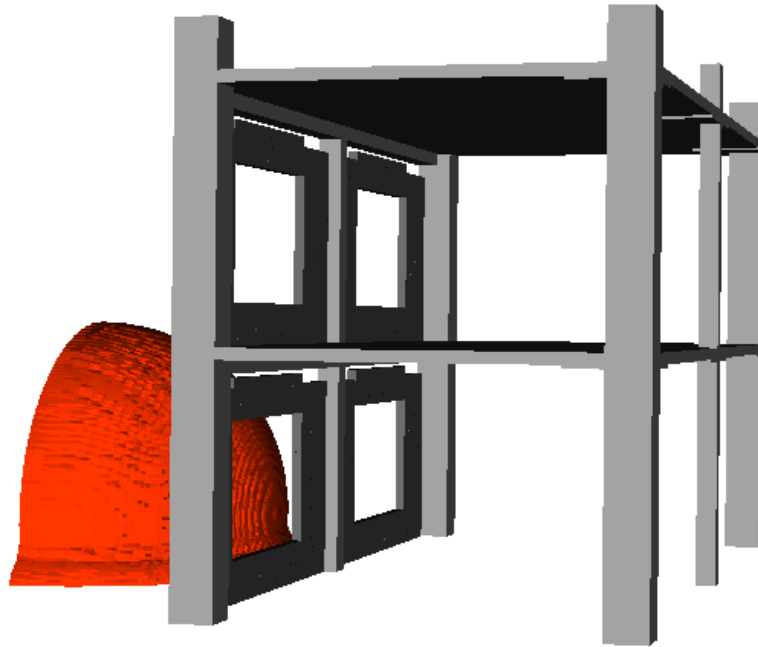
# ZAPOTEC

- Coupled Code (CTH/PRONTO) written in Fortran 90.
- Original Code not suitable for Massively Parallel Computer Platforms.
- Project with several others to modify the code to work on Massively Parallel Platforms.
- Modifications on set of variables that need to be exchanged between CTH and PRONTO.
- Reduced the number of CTH materials required for Lagrangian Material Insertion.
- Modified CTH to NOT call the EOS for Lagrangian Materials.
- Added Momentum Transfer using Half Index Shifted (HIS) Momentum scheme (PRONTO to CTH).

# ZAPOTEC (Cont'd)

- **Added Mass weighted Stress Deviator Transfer (PRONTO to CTH). Consistent with CTH treatment.**
- **Added von Mises radial return stress deviator adjustment to ZAPOTEC using the strength values from CTH. This prevents including stress deviator values that cannot be supported by the Eulerian materials.**
- **Participated in a Coupled Code Conference (Sponsored by DTRA) in La Jolla. I was assigned duty as the Eulerian Module Chair (attended with Steve Attaway and Courtenay Vaughan).**
- **Helped Courtenay install and explain ZAPOTEC at ARL.**
- **Presented (with Steve) ZAPOTEC Capabilities to CIA.**
- **Have version that works with the latest Adaptive Mesh Refinement (AMR-CTH) in Conventional and “Genless” modes. Continuing work to allow full AMR capability.**

# ZAPOTEC: THE MOVIE



# CTH – NSWC

## (Naval Surface Warfare Center)

- NSWC interested in Reactive Fragments (Long time events, out to several milliseconds).
- CTH Time step (DT) is based on sound speed (C) and material velocity.
- DT for advection dominated flow need not depend on sound speed.
- Modified DT determination by adding a multiplier ( $0.0 < \text{ALPHA} \leq 1.0$ ) to C based on local conditions (local pressure gradients).
- The maximum ALPHA found in the mesh is kept and the pressure (and stress deviator) gradients are multiplied by this ALPHA squared in the momentum update.

# CTH – NSWC (Cont'd)

- The Transmissive boundary condition (1) in CTH also needed to be modified by multiplying the C terms by this maximum ALPHA.
- The speed up for a moving blob of different density air is about a factor of 5.
- We still do not understand why the C dominated DT results in CTH are so poor (compared to the adjusted DT results).



# Preconditioning Methodology

$$\partial u / \partial t = -(1 / \rho) \partial P / \partial x$$

$$\Delta u / \Delta t = -(1 / \rho) \Delta P / \Delta x$$

**Find the change in pressure that will yield a change in velocity equal to the sound speed.**

$$\Delta P c = \rho \Delta u \Delta x / \Delta t$$

$$\Delta P c = \rho C \Delta x / \Delta t$$

**Define alpha as a function of local conditions.**

$$\alpha = (\text{arbitrary constant}) | \Delta P / \Delta P c |$$

**Apply suitable limits on alpha and use alpha as a multiplier on the sound speed in determining the new time step.**

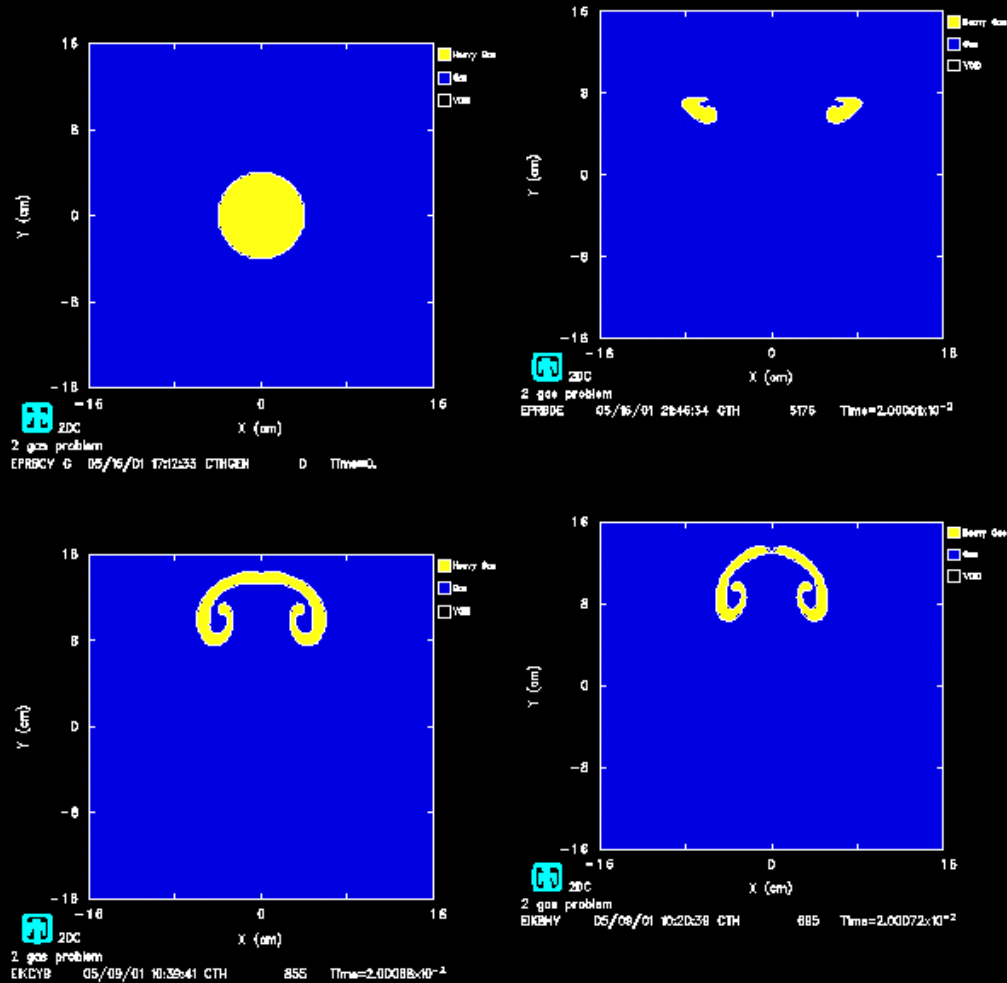
$$\Delta t = \Delta x / (|u| + \alpha C)$$

**For consistency the maximum alpha in the mesh must be stored and alpha squared is used as a multiplier in the momentum update.**

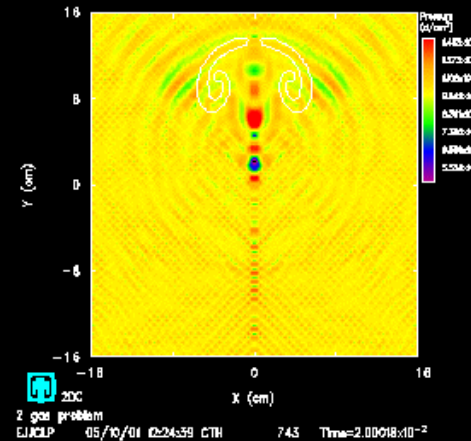
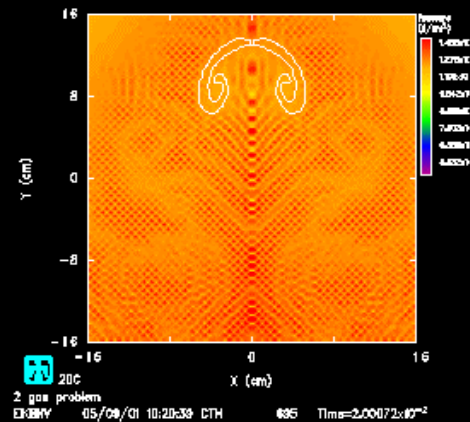
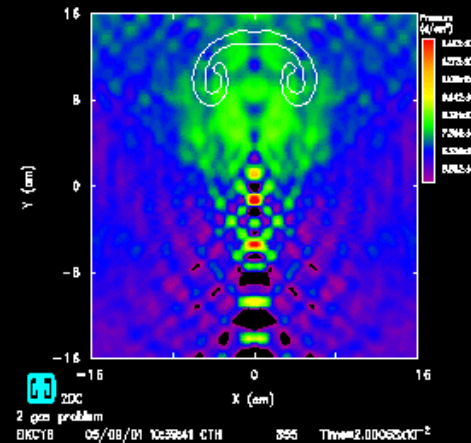
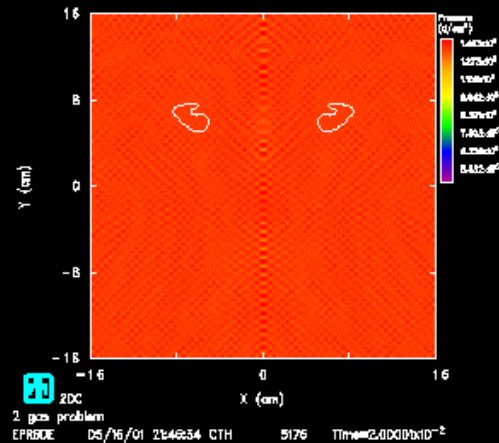
$$\Delta u / \Delta t = -(1 / \rho) (\alpha_{\max}^2) \Delta P / \Delta x$$

**This same maximum alpha is used as a multiplier to the sound speed in the transmissive boundary condition routine**

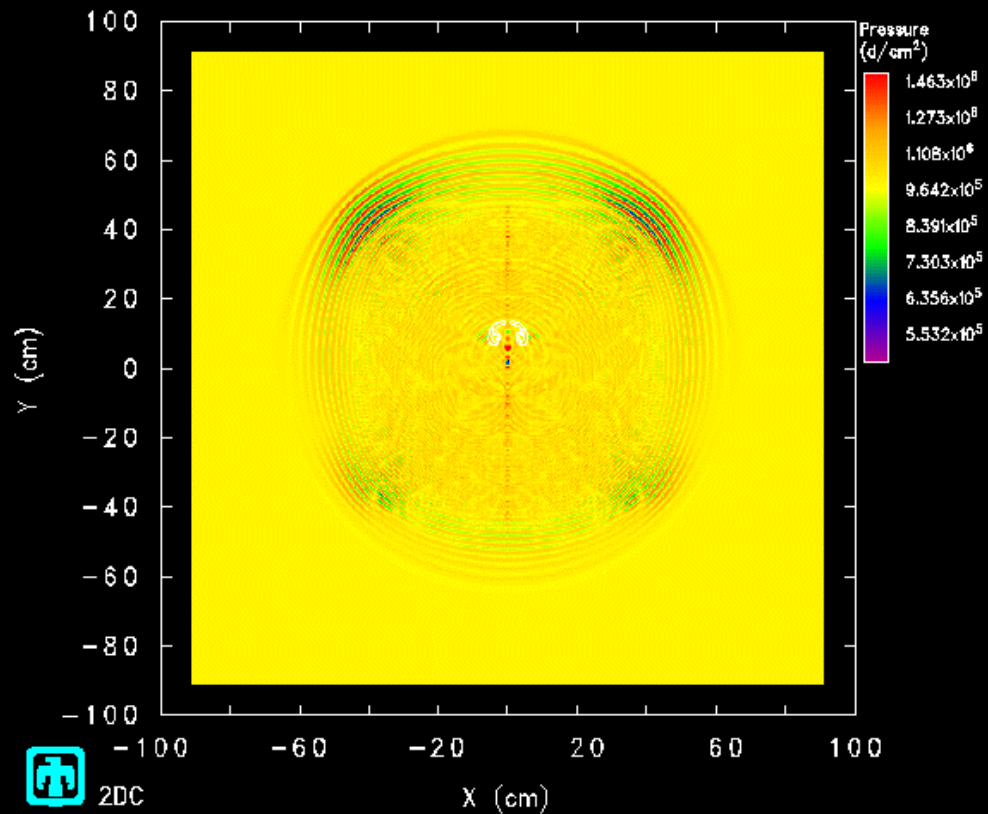
# Time Step Control Comparisons



# Time Step Control Comparisons



# Time Step Control Comparisons



2DC

2 gas problem

EJCLP 05/10/01 12:24:39 CTH

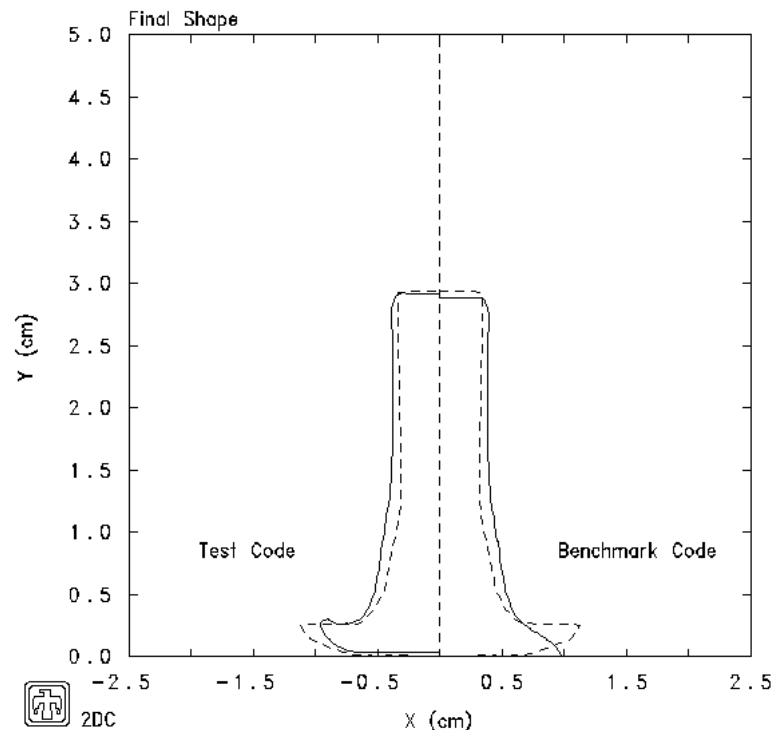
743 Time=2.00018x10<sup>-2</sup>

# CTH - General

- **Tracked down MANY bugs (Tracer Point Errors).**
- **Assisted other developers with their modifications.**
- **Created new MMP3 option (essentially a simplified MMP2 that does not require EOS call, MMP3 is now the backup for MMP2 if the EOS call fails).**
- **Working with AMR-CTH to make it compatible with ZAPOTEC.**

# FEB01 CTH: Boundary Conditions

- Non-stick reflective boundary
  - permits impacting body to “bounce” off rigid boundary



Taylor Test: Tantalum, SGL model, V=250m/s (pataylo)

# FEB01 CTH: Boundary Conditions

- Periodic boundary condition
  - Effectively extends material microstructure features beyond mesh boundary
  - Useful for simulating material with explicit microstructure



# FEB01 CTH:

## Convection Options

- New Energy/Momentum Convection Options
  - Total Energy Convected (Momentum conserved)
    - Option 1: subtract off KE defined with cell-centered velocities
 
$$KE = \frac{1}{8} m_{i+1/2} [(v_i + v_{i+1})^2]$$
    - Option 2: Subtract off cell-centered KE
 
$$KE = \frac{1}{4} m_{i+1/2} [(v_i)^2 + (v_{i+1})^2]$$
    - Result: Internal Energy convected w/ KE residual
- Original energy convection option still available
  - Internal energy convected (van Leer), KE ignored, momentum conserved







# FY01 Department 9232 Review

David Crawford



May 30, 2001



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,  
for the United States Department of Energy under contract DE-AC04-94AL85000.



# Overview

- Status of AMR
- Improving AMR usability
  - User's Guide
  - User Training
  - New parallel post-processing capability (spyplt)
- Example 2-D and 3-D AMR CTH calculations
- Performance improvements
- Future and proposed code developments
  - Further enhance improvements
  - Reduce memory requirements

# AMR CTH

- Block-based
- Generalization of MPCTH (with multiple blocks per processor)
- Isotropic 2:1 refinement/unrefinement
- Single time-step for all blocks
- User specifies global dimensions of mesh, maximum number of allowed blocks (per processor) and block dimensions ( $N_x$ ,  $N_y$ ,  $N_z$ )
- Load balance on per-block basis (don't split blocks across processor boundaries)

# Status of AMR

- AMR version 1.00 has been released externally:
  - includes on-the-fly and post-process visualization using Spymaster.
  - unlimited block allocation (Millie Elrick)
  - user-definable generalized indicators
  - does not include Zoltan or other recent performance enhancements.
- Production AMR will shortly include:
  - significant performance enhancements
  - Zoltan
  - 3-D visualization improvements

# AMR Usability

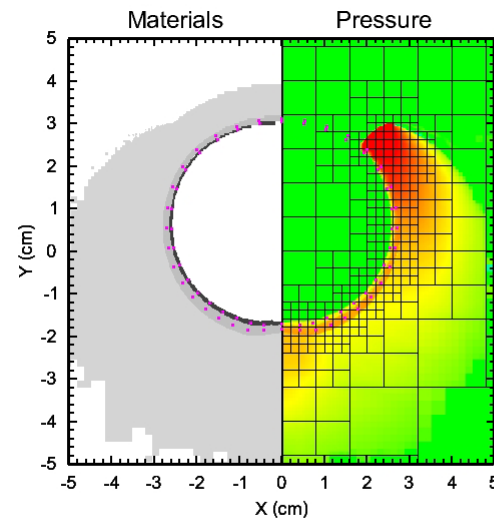
## *generalized indicator syntax*

...

- \* Use histogram of max.
- \* pressure difference
- \* across cell as refine/
- \* unrefine indicator

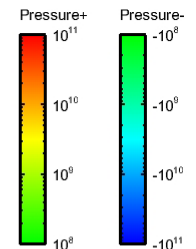
```
indicator
  diff pressure
  vmin 1e8
  logh
  refabove 0.95
  unrbelow 0.5
  ton 0.5e-6
endi
```

```
enda
```

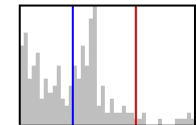


Time = 1.02e-05

Cycle = 2397



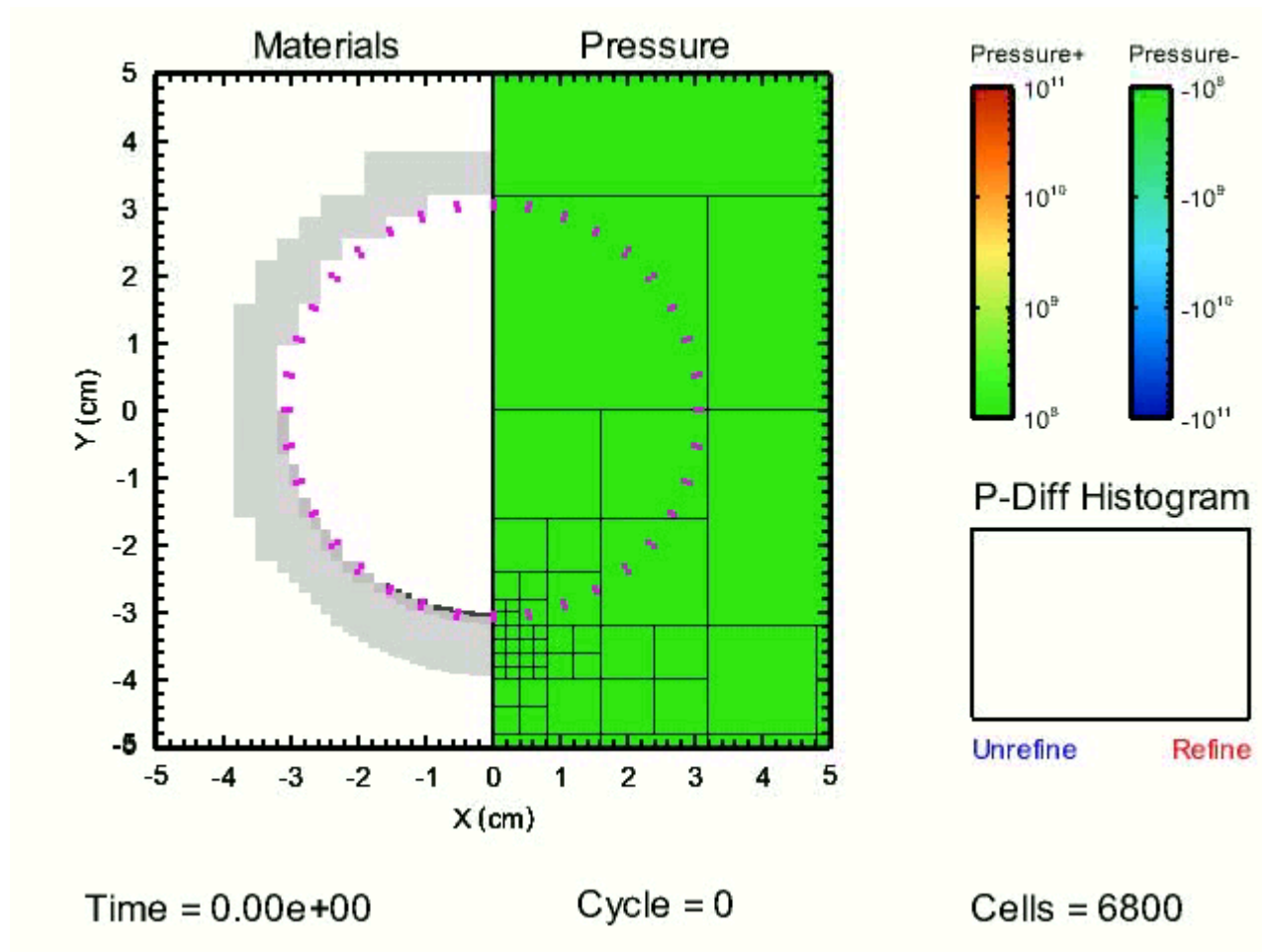
P-Diff Histogram



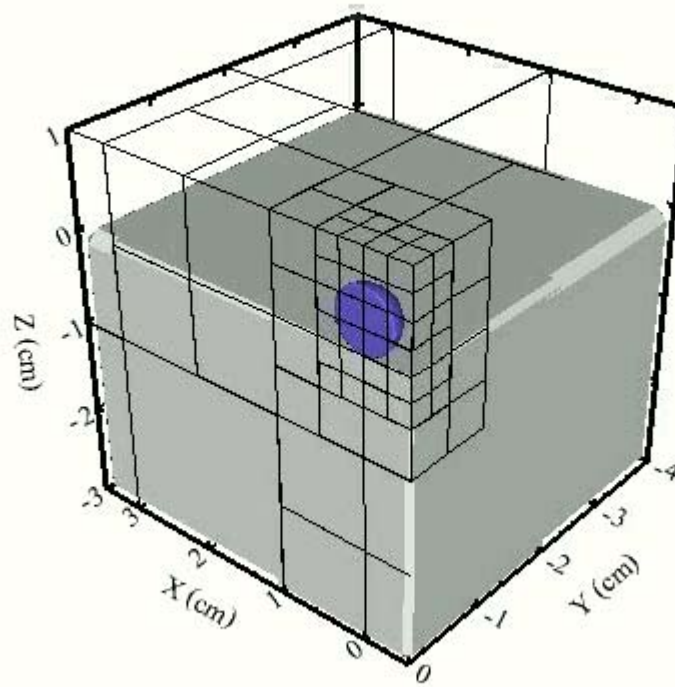
Unrefine Refine

Cells = 34100

# Single Point Initiation: THE MOVIE

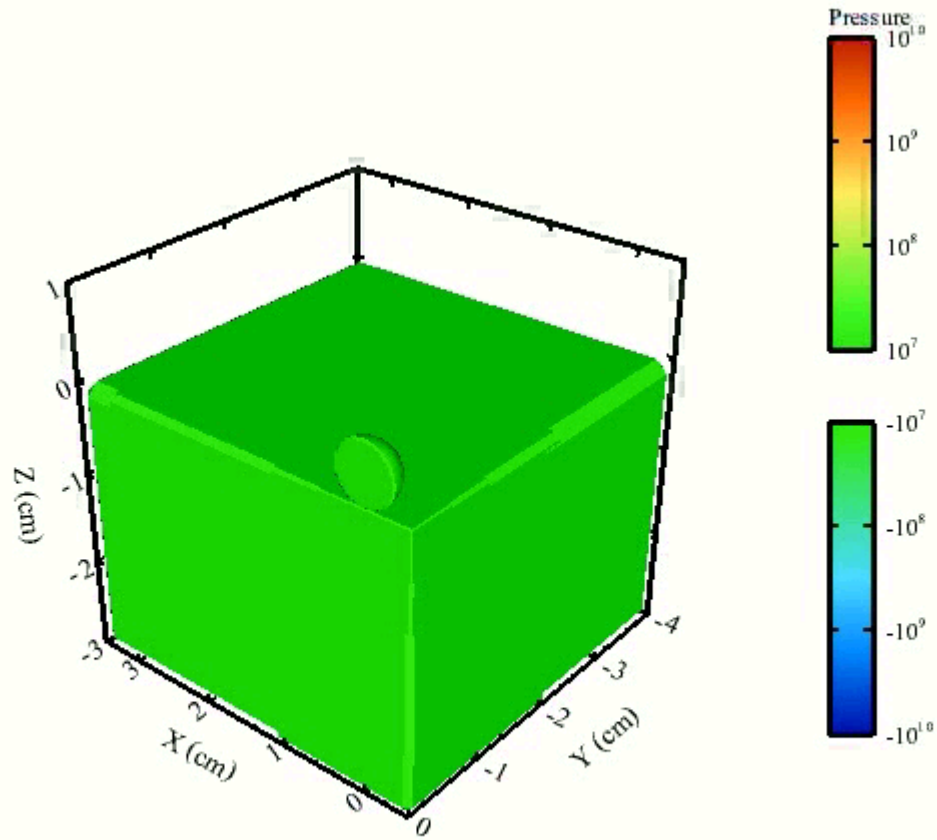


# Oblique Impact: THE MOVIE



0.00e+00 secs.

# Oblique Impact (cont.): THE MOVIE



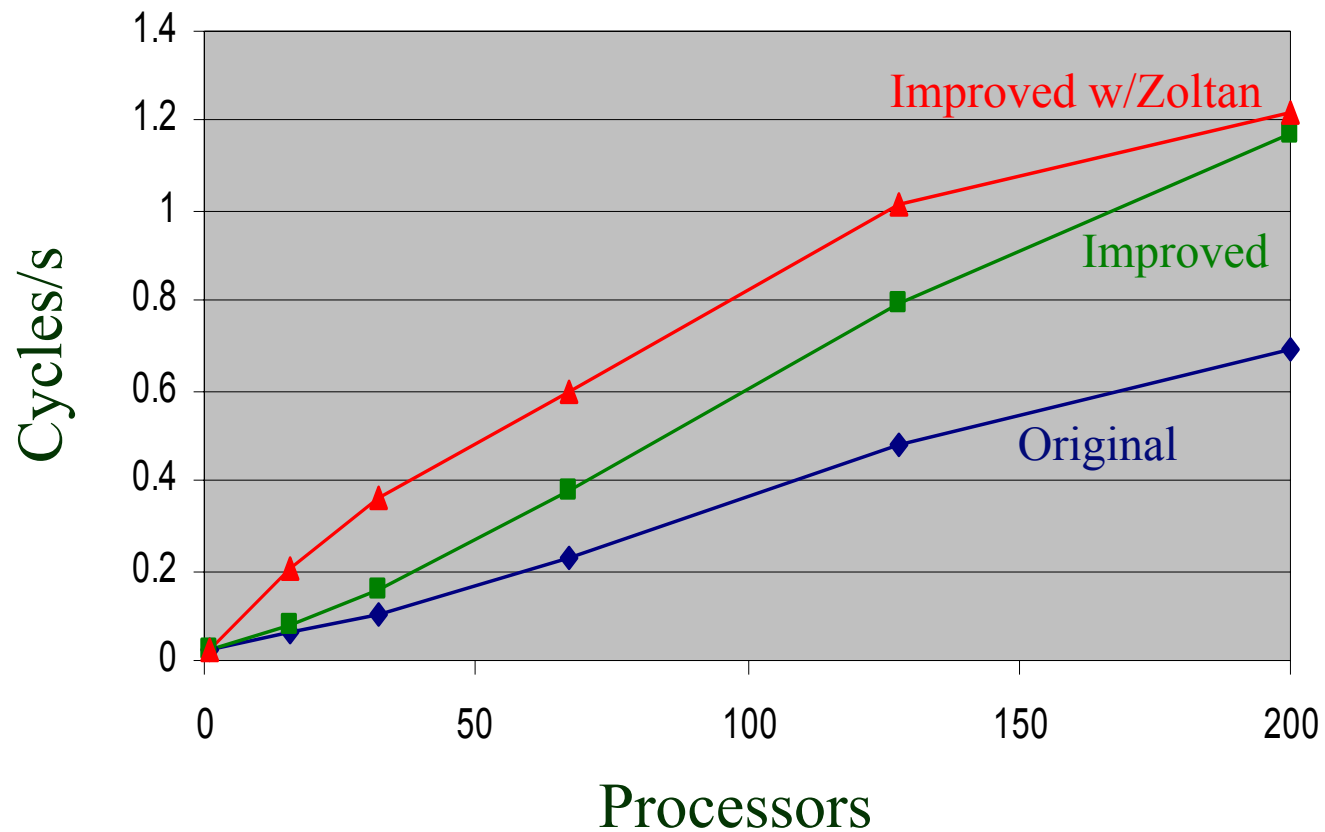
0.00e+00 secs.



# Performance Improvements

- Parallel process block refinement/unrefinement as much as possible
  - perform refinement only once every 3 cycles
  - perform unrefinement only once every 6 cycles
  - increase refinement border to 2 cells to accommodate this
- Perform load balancing only when disparity is more than 10%.
- Use Zoltan to minimize off-processor communications.

# Performance Improvements



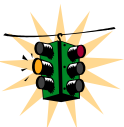
# Proposed Code Developments

- Consolidate AMR message passing to reduce latency
- Reduce size of message buffers
  - allocate space for receive buffers only, re-use send buffers
  - update only a few variables at a time
- Allow blocks to allocate space for only those materials needed (CTH U Alegria)
  - presently space is allocated for all materials in every block

# Future Code Developments:

## CTH **U** ALEGRA (w/ Mark Christon)

- Add new structured-region class to ALEGRA.
  - Multiple regions contain blocks of finite-difference cells (equivalent to AMR CTH blocks).
  - Use CTH legacy Fortran to solve physics, constitutive models, etc. within each block.
  - Use C/C++ to handle interface between blocks.
  - Use ALEGRA superstructure to handle memory management, scratch variable allocation, load balancing of elements, etc.
- ALEGRA parser for user input.
- DIATOM for material insertion.
- Spymaster for visualization.





# FY01 Department 9232 Review

Stewart Silling



May 30, 2001



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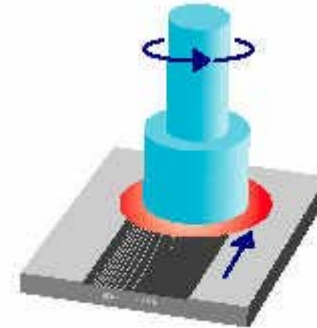
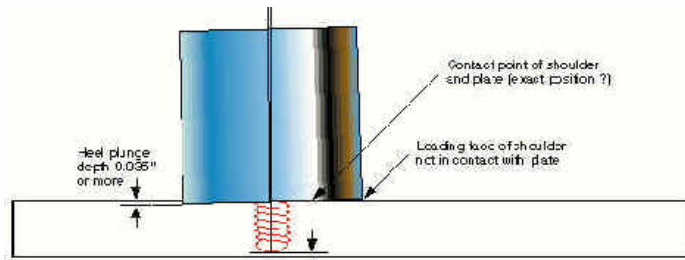


# FY01 Projects

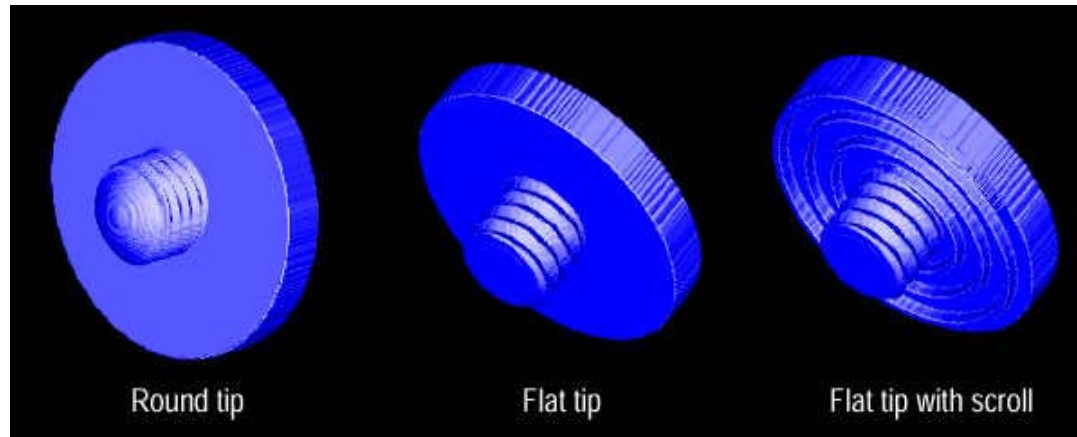
- Methods development
  - Modeling of friction stir welding NFE/WFO - Boeing
  - Peridynamics MOU, CSRF
  - CTH/EPIC support MOU
  - CTH shear band model WFO – Army
- Applications
  - High-G penetrator DP
  - Concrete breaching/blasting WFO - Army
  - EPW model benchmark DP, MOU

# Friction stir welding model

- A new technology that may revolutionize the way planes are built.
- Joins aluminum plates or shells without melting.

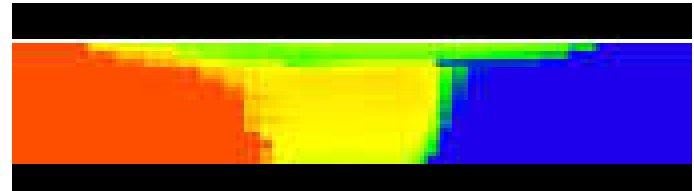
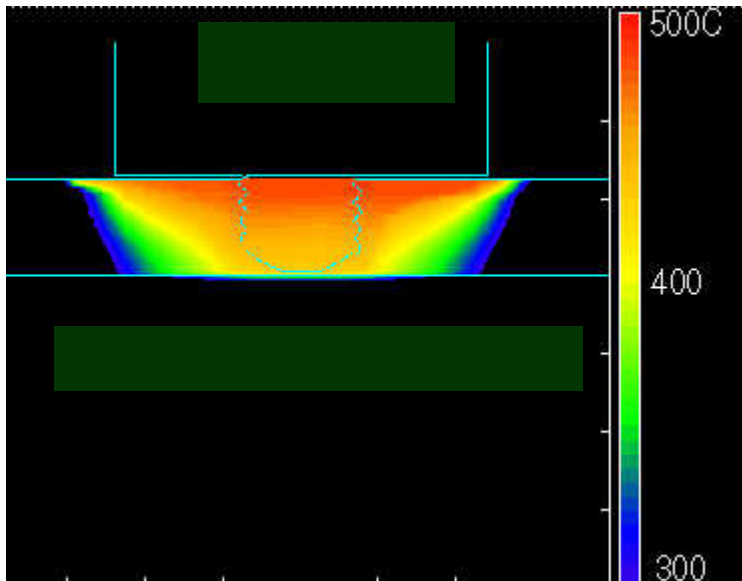


Some tool shapes (CTH model):



# Friction stir welding model: Technical approach

- CTH: prescribe velocities in tool and at mesh boundaries.
- Operator splitting: alternately solve for...
  - Velocities (using CTH)
  - Temperatures (using convection-diffusion solver).



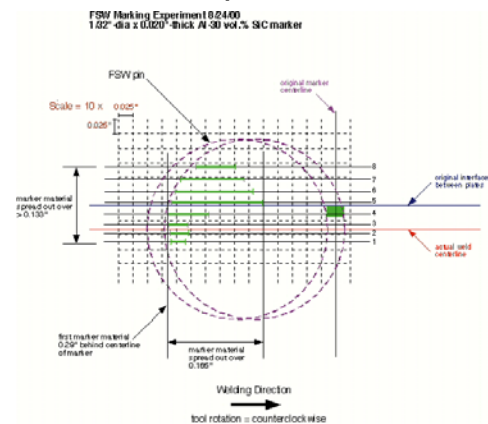
Mixing (computed)



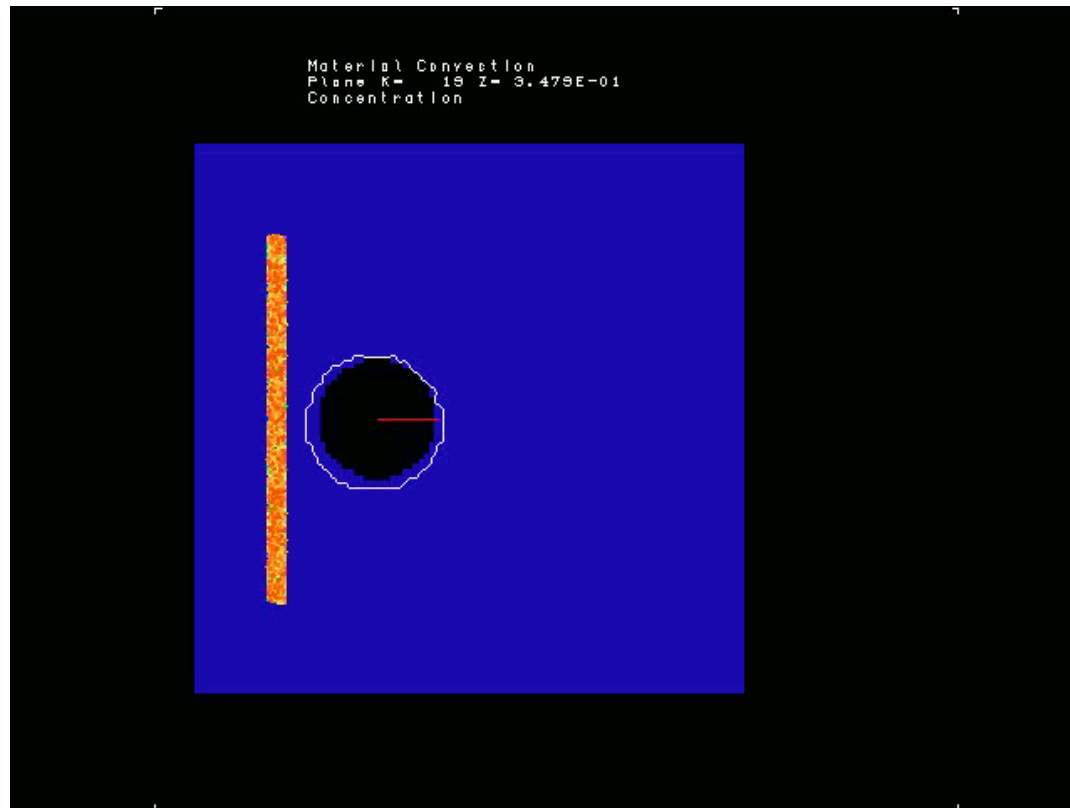
Photograph of cross-section



- Tracer particle experiments (Rockwell Science Center):



# Friction stir welding: THE MOVIE



# Friction stir welding model:

## Status

- **A version of the model has been delivered to the sponsor.**
  - **16-node SGI**
  - **16-node DEC alpha cluster**
- **This project is critical in establishing a new CRADA with Boeing.**
  - **This will bring in business to diverse areas at Sandia.**
  - **Will result in closer relationship between SNL and the aerospace industry.**

# Peridynamic modeling

## Objectives

- Develop a theory of continuum mechanics in which the same equations hold on or off of any discontinuities.
- Provide a useful code based on this theory.

## Why

- Enable modeling of spontaneous discontinuities such as cracks without special techniques.
- These singularities are crucial to material failure.

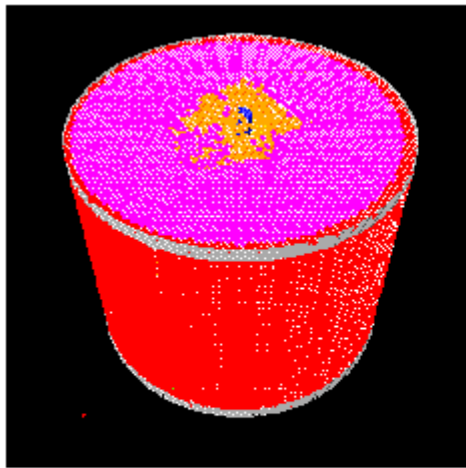


THE MOVIE

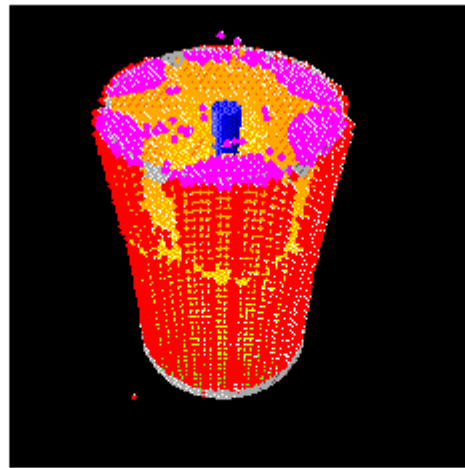
# Peridynamic applications:

## Target size effect for earth penetrators

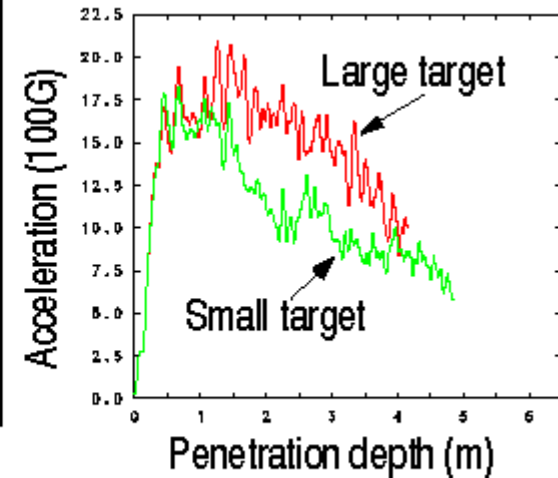
- How big does a target have to be to reproduce half-space response?
- Discrete nature of crack growth has an important effect:



Large target  
15 penetrator diameters

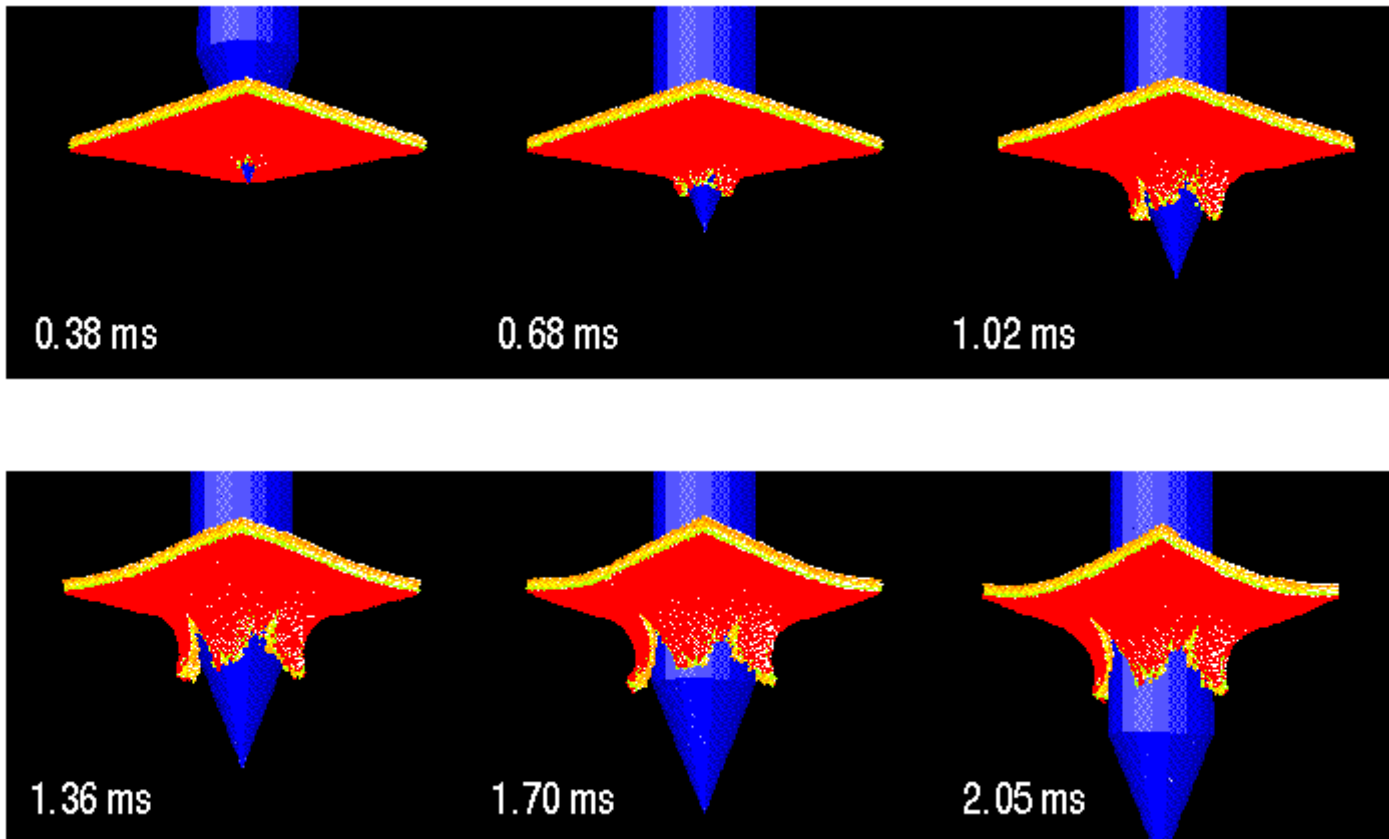


Small target  
7.5 penetrator diameters



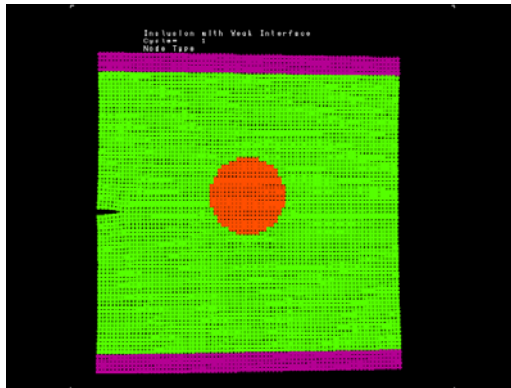
# Peridynamic applications: Petaling

- Perforation of thin ductile plates often results in a family of radial cracks.

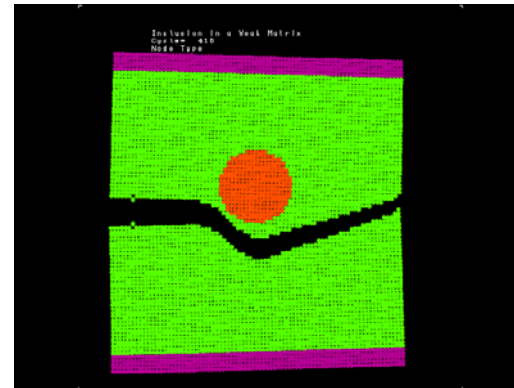


# Peridynamic applications: Composite material failure

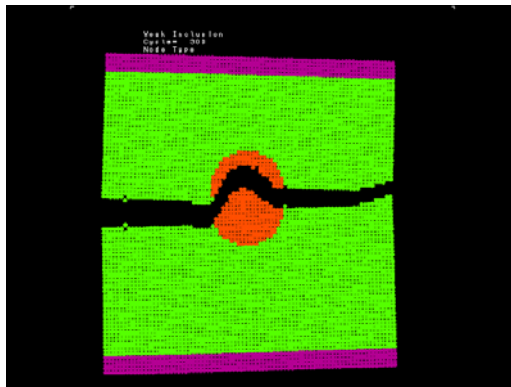
- How do the relative strength of the matrix, fibers, and interfaces affect crack growth?



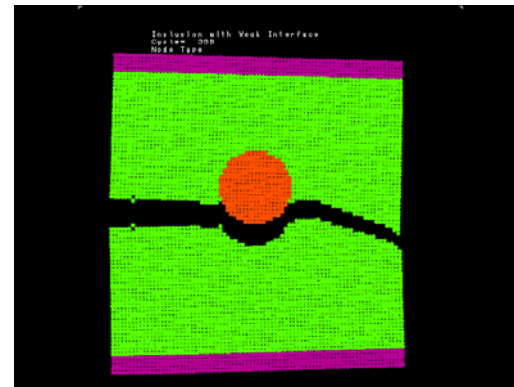
Initial crack



Weak matrix

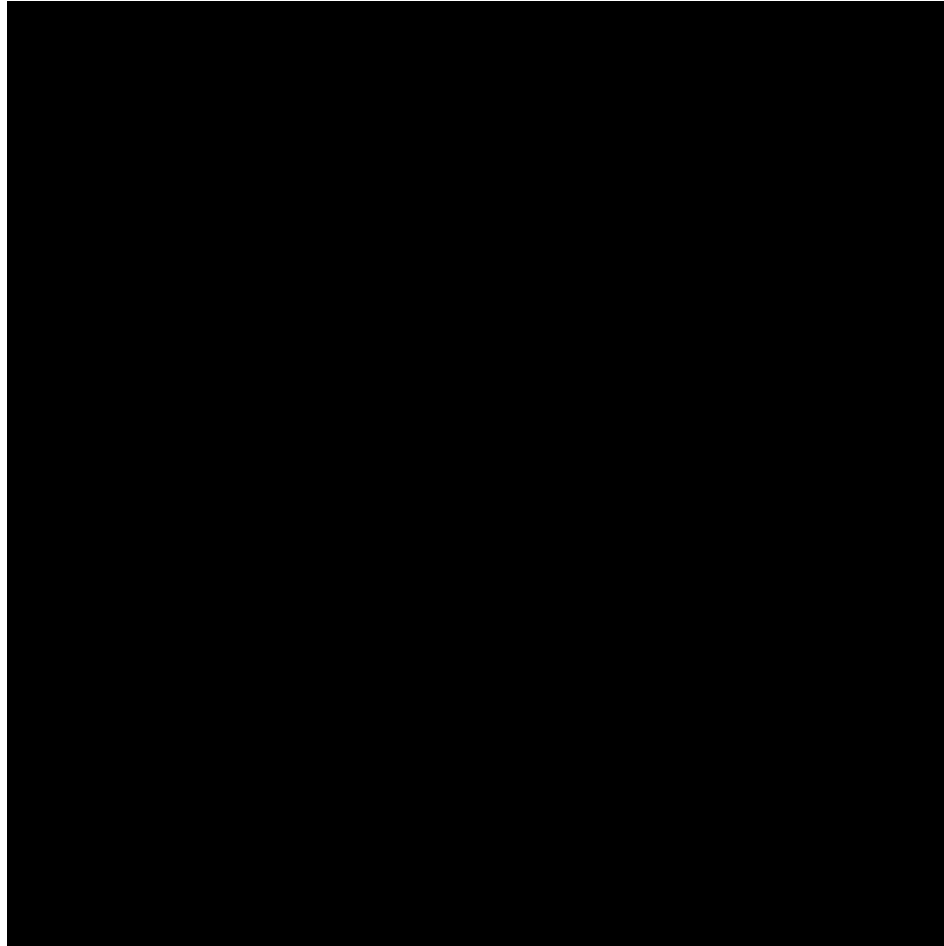


Weak fiber



Weak interface

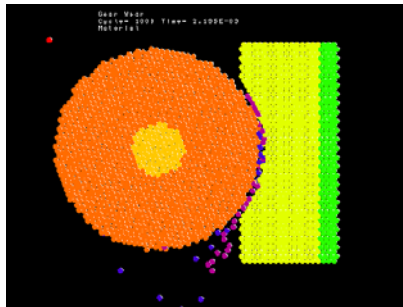
# Composite material failure: THE MOVIE



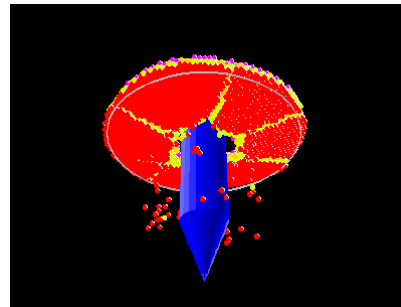


# Peridynamic model: Status

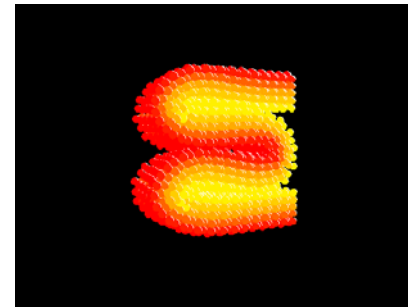
- Continuing to develop the theory and code.
  - SNL: fracture mechanics, numerics, code development.
  - MIT: modeling of material defects.
  - Caltech: incorporation of atomistic physics.
- Code is being applied to real-world problems.
  - Potential customers include...
    - ARL: armor
    - Boeing: fatigue cracking, shell impact problems, composites
    - EPW programs: brittle target penetration
    - MEMS: wear, stiction



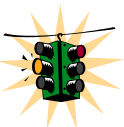
**Wear**



**Perforation**



**Folding**





# FY01 Department 9232 Review

Marlin Kipp



May 30, 2001

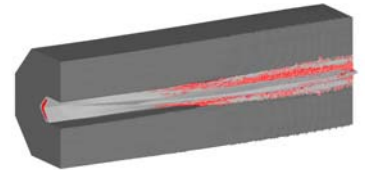
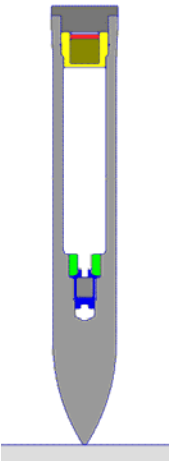


Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,  
for the United States Department of Energy under contract DE-AC04-94AL85000.



# FY01 Projects

- NEST / Source Term Mitigation ~  
Applications to silver surrogates, modern weapon  
Contributions to field events
- Porous Material Modeling ~ Glass microballoon  
Explicit pore inclusion / shock response
- Penetration Modeling ~  
WES penetrator / concrete experiments (MOU)  
Other Support ~  
End point data transfer to monitor component  
performance in high-fidelity JTA's  
Shaped charge / structural loads (WFO, w/ 9120)  
Consistent fragmentation model parameters that represent  
both sphere impact and shell expansion breakup (NSWC)



# NEST Background

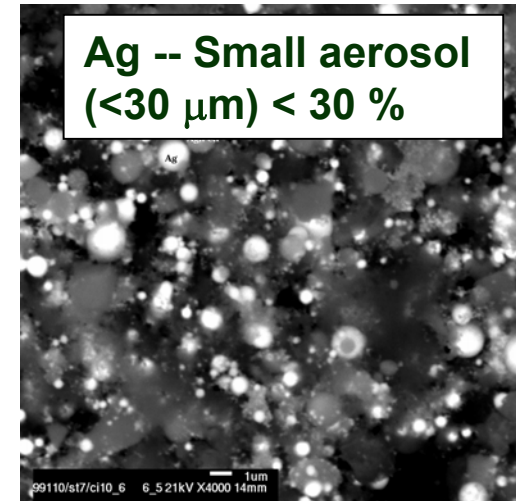
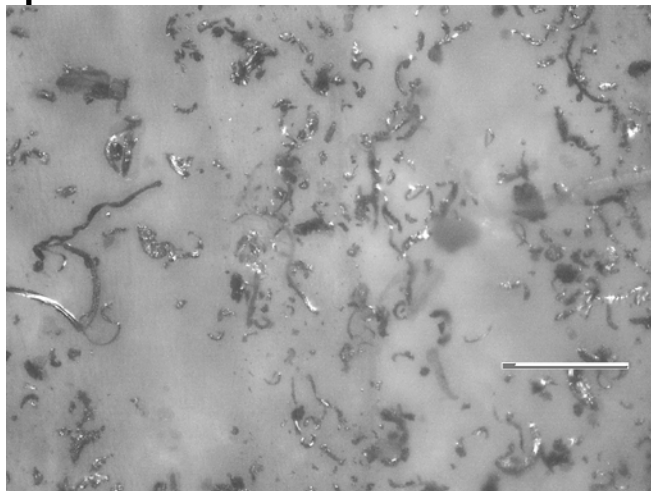
- Use device-specific information on materials and geometry with field tools and/or simulations to assess potential mass fraction of radiological material released as aerosol ( $<30\mu\text{m}$  aerodynamic)
- Source term aerosol formation from detonated device
  - Prompt formation of solid/liquid/vapor fractions, fragments  
(Time scale: microseconds)
  - Debris transits explosive products into atmosphere  
(Time scale: milliseconds)
  - Dispersal of aerosol  
(Time scale: seconds)
- CTH simulations of devices being used to construct reliable tools for field applications (on-going)

# Example of Data Collected in Silver Experiments

- Majority of mass for single shell experiments is large chunks (solid fracture), or small aerosol (liquid breakup, vapor condensation)

- CTH ~ 26% liquid / 1% vapor

Data: Ag -- Intermediate particles (30 - 100  $\mu\text{m}$ ) < 1 %  
vapor

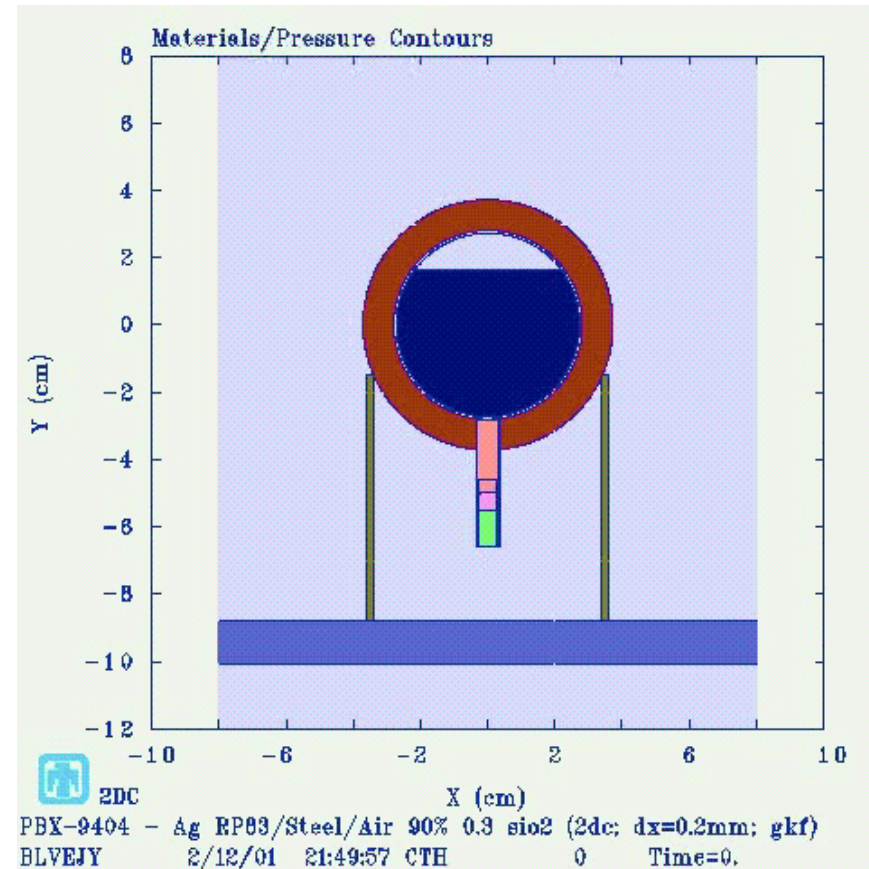


# Silver / GMB / PBX-9404 - 2dc

## CTH

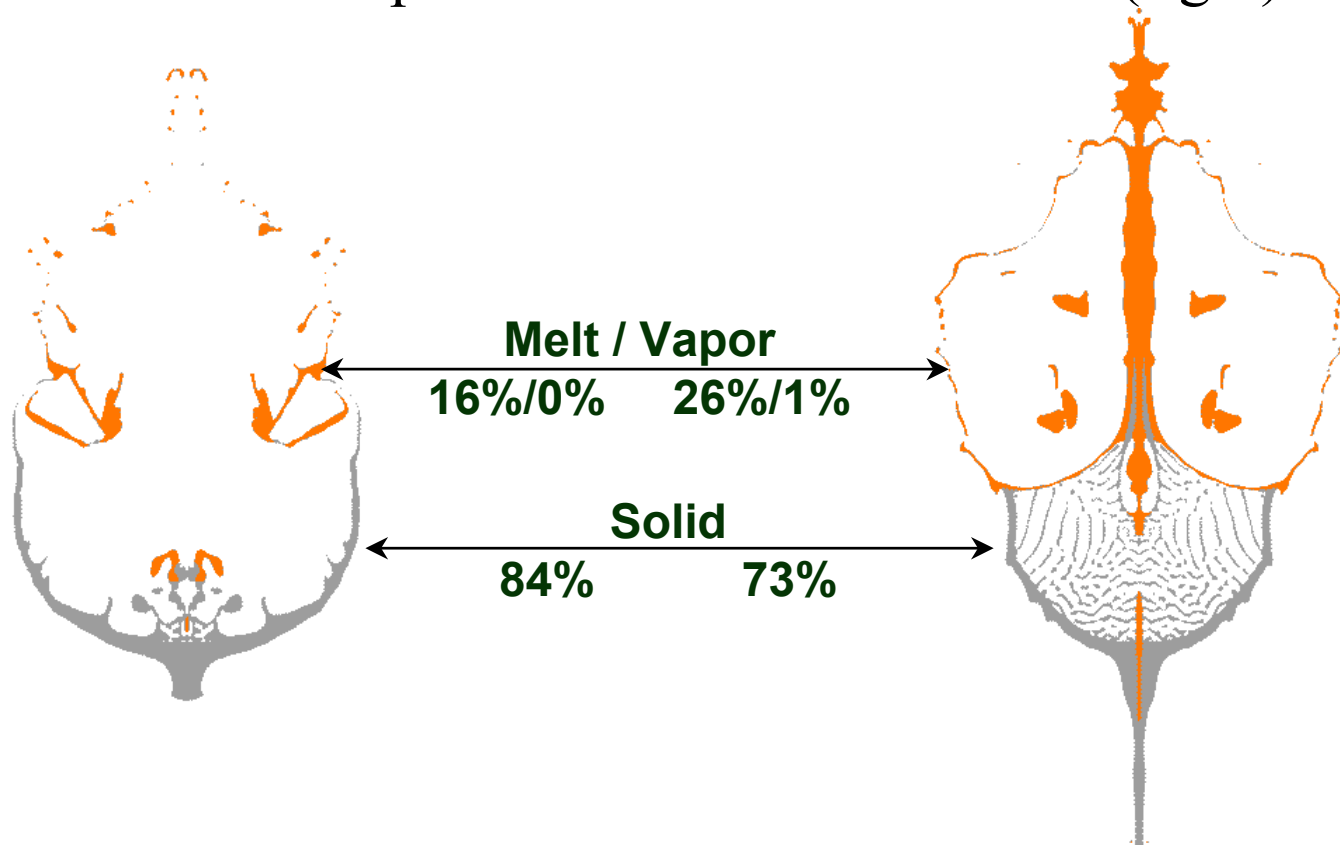
### THE MOVIE

- Spherical silver shell (0.9mm, 80g) inside 9mm layer of PBX-9404 (220g)
  - 90% volume fill GMB (24.9g) (porous glass model,  $0.3\text{g/cm}^3$ )
  - 1-point initiation
- CTH - 2dc,  $\Delta x=0.2\text{mm}$ 
  - Presence of glass prevents full collapse of silver
  - Reduces, but does not eliminate, fractions of liquid / vapor formed



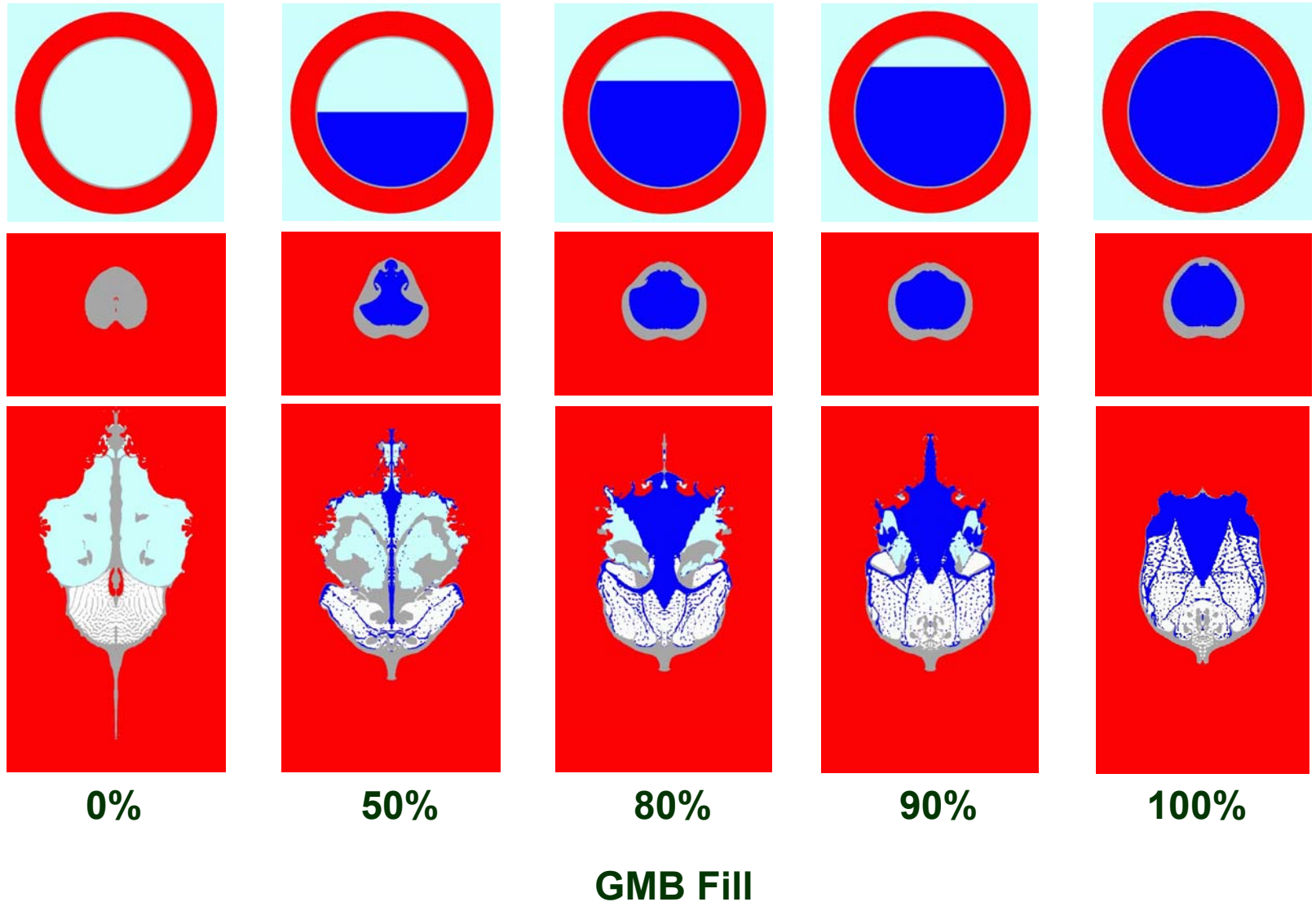
# Silver / GMB / PBX-9404 - 2dc CTH

- Presence of 90% GMB fill (left) alters silver expansion characteristics compared with unfilled baseline (right)





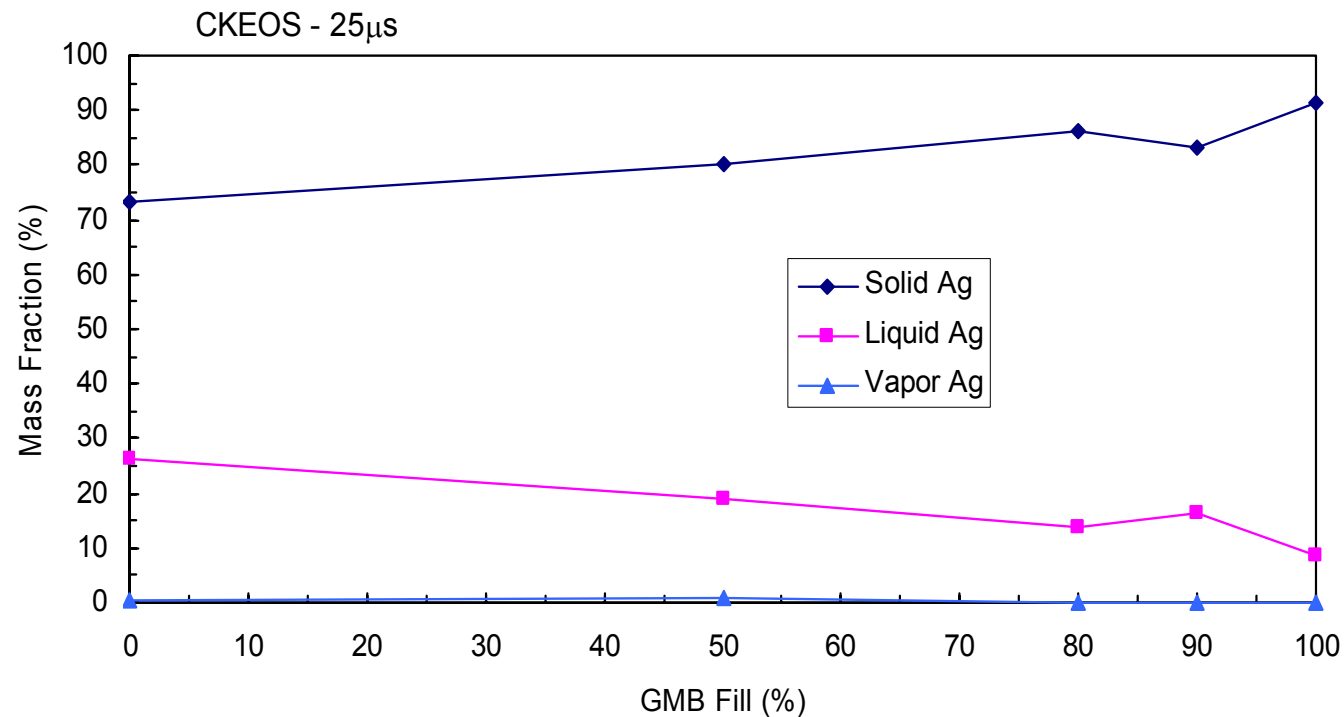
# Effects of GMB Fill Volume: 1-Pt Initiation





# Silver Solid/Liquid/Vapor Fractions vs. %GMB

- Increased GMB fill volume generally leads to formation of less liquid / vapor compared to unfilled baseline
- Quartz fill initial density:  $0.325\text{g/cm}^3$  (solid density:  $2.204\text{g/cm}^3$ )



# Silver Solid / Liquid Initial Fragment Sizes

Solid - Toughness:  $S = \left( \frac{\sqrt{24K}}{\rho c \dot{\epsilon}^2} \right)^{1/3}$       Yield:  $S = \left( \frac{1.2Y}{\rho \dot{\epsilon}^2} \right)^{1/2}$

$$S = \left( \frac{48\gamma}{\rho \dot{\epsilon}^2} \right)^{1/3}$$

Liquid – Toughness:

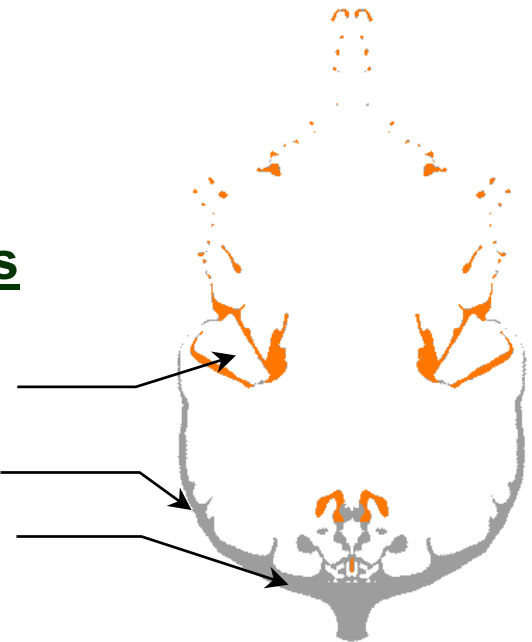
## Silver Fragment Sizes / Ejection Velocities

10 - 50 $\mu$ m (liquid) (2700m/s)

Solid: 1.4mm (shell) - 140 $\mu$ m (interior) (1000m/s)

Solid: 1.8mm (shell) - 500 $\mu$ m (interior) (800m/s)

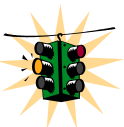
(Liquid velocities exceed aerodynamic breakup criteria in explosive product and air environments)



# NEST / Source Term Mitigation

## Summary

- Contributions to field events:
  - Application to LANL hydrotest device ~  
Request to estimate aerosol releases for U / Be materials  
Preliminary results consistent with CTH predictions:  
Some U, no Be aerosol formation
  - SLC Olympics dispersal incident training exercise ~  
Contributed to database of material response to explosive sources (e.g., ceramic fuel rods, toxic metals)
  - Response to concern for potential accident involving a Mk15 lost in the Savannah Delta (Georgia) in the 1950's ~  
Provided estimated source term release of SNM for worst case scenarios.





# FY01 Department 9232 Review

Rebecca Brannon



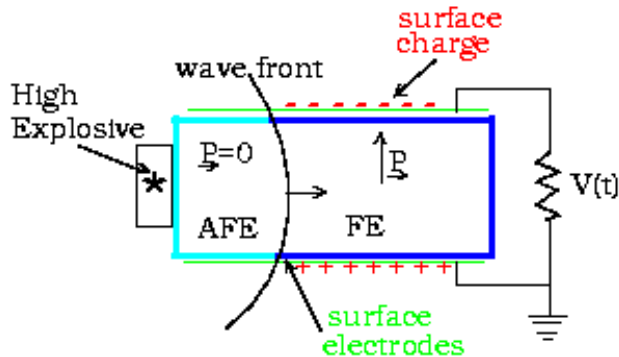
May 30, 2001



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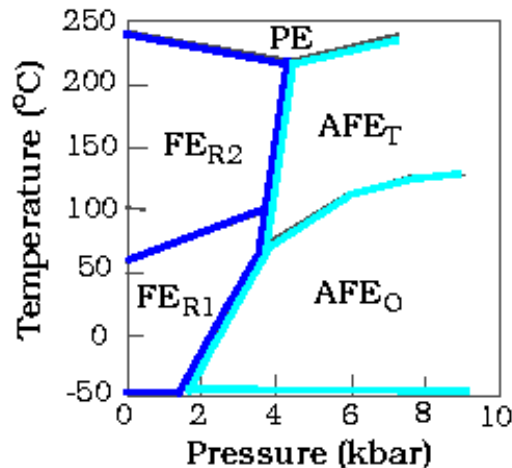
# Principle of Power Supply Operation



- Power Supply Operating Principle: Shock-Induced Depoling.

- Phase behavior of PZT is key.

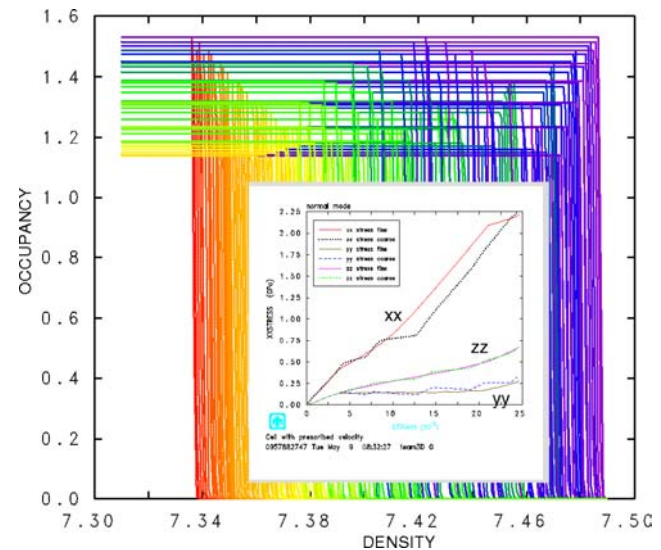
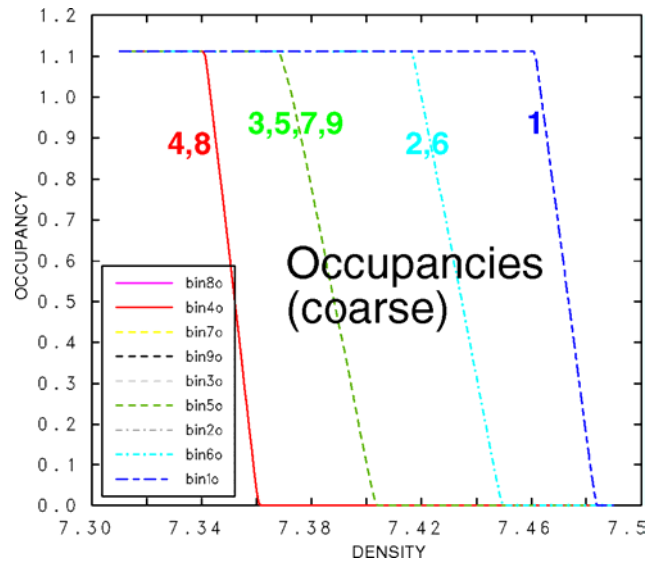
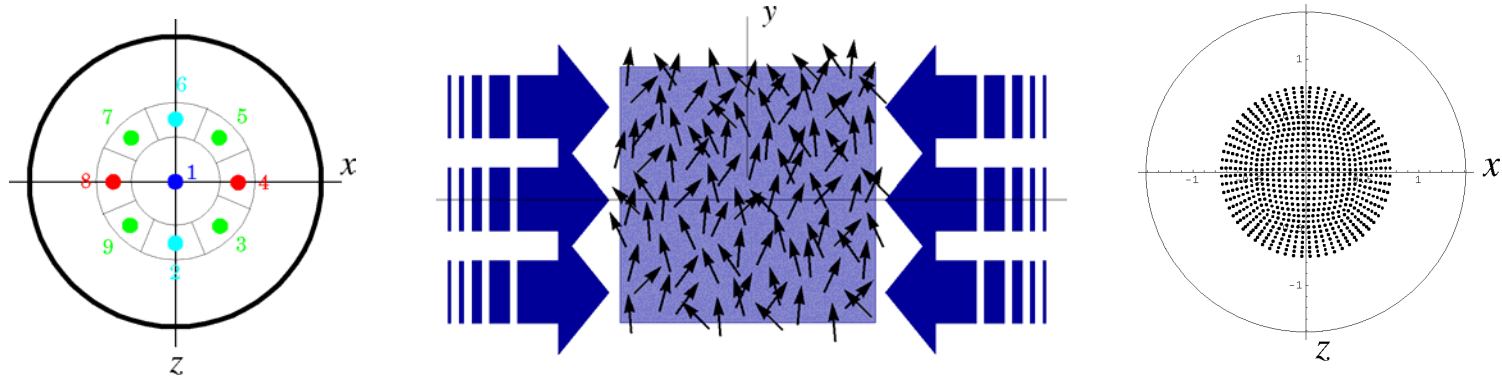
[phase diagram after Fritz & Keck, J.Phys. Chem. 39, 1163 (1978)]



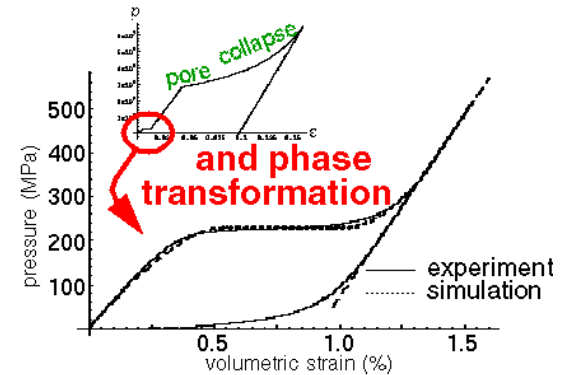
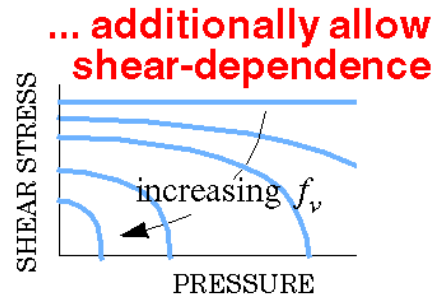
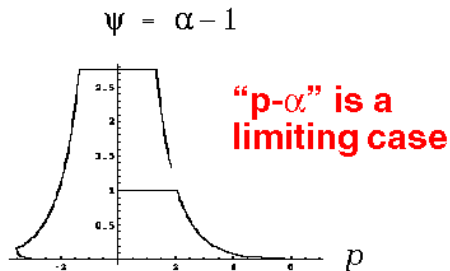
## Hallmarks of Ferroelectrics

- Spontaneous polarization constrained to specific lattice directions.
- A **DOMAIN** is a region of uniform polarization within a crystal.
- Polarization can switch by twinning under applied stress or E-field

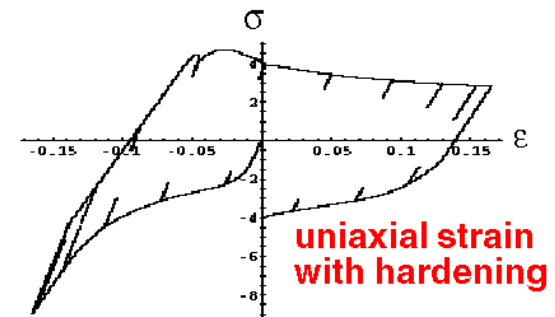
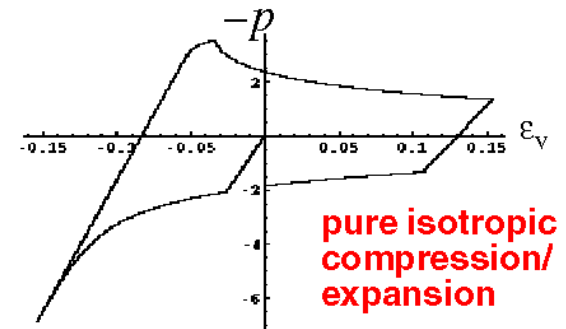
# Modeling dipole distributions



# The porosity model



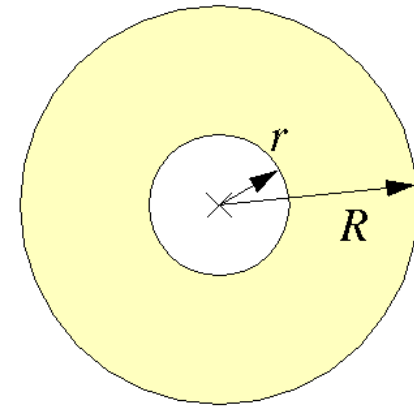
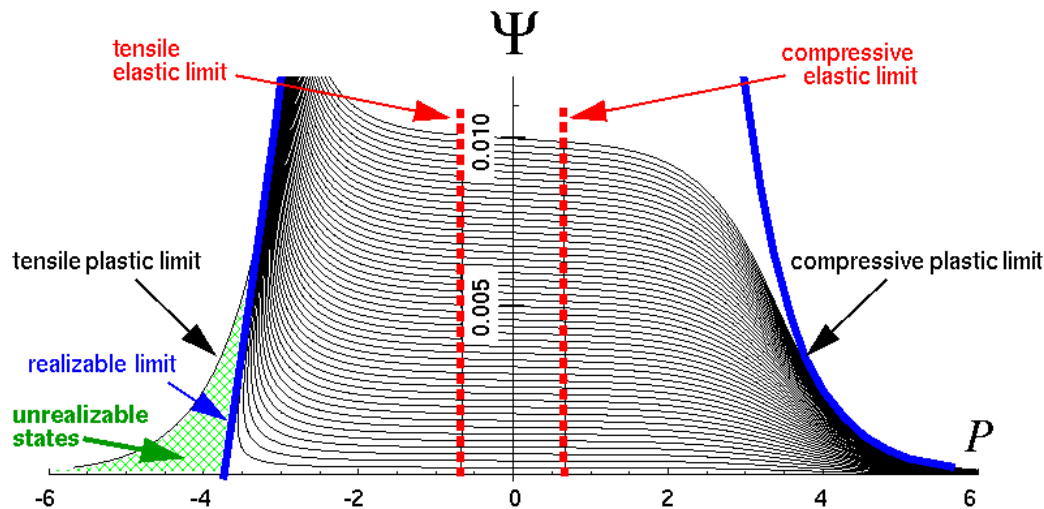
- Shear-dependent crush:  $F(p, \tau, \psi, \varsigma) = 0$
- Positive dissipation  $d_p^G = \dot{\lambda}[F_m \hat{I} + F_s \hat{S}]$
- Strain-Pore coupling:  $\psi = (1 + \psi) \text{tr} d_p$
- Nucleation (ad hoc):  $\psi^N \propto \frac{\sigma_m}{\varepsilon^N K_m (1 + \psi)} - 1$
- Consistency:  $F_m \dot{\sigma}_m + F_s \dot{\sigma}_s + F_\psi \dot{\psi} + F_\varsigma \dot{\varsigma} = 0$
- Pore-dependent stiffness.  $\frac{K}{K_m} = e^{-\kappa_m \psi}$
- Phase transformation:  $d^T = \dot{r}[T_m \hat{I} + T_s \hat{S}]$
- Rate dependence:  $\dot{\sigma}_{ij}^{\text{over}} = q_{ij} - \frac{\sigma_{ij}^{\text{over}}}{\tau}$



# Recent Analytical Work on the CKP model

Hollow sphere model: uniform outer pressure  $P$ .

Yield begins at the inner radius (elastic limit). Increased pressure propagates the plastic zone to the outer radius (plastic limit).



$$\text{porosity: } f = \left(\frac{r}{R}\right)^3$$

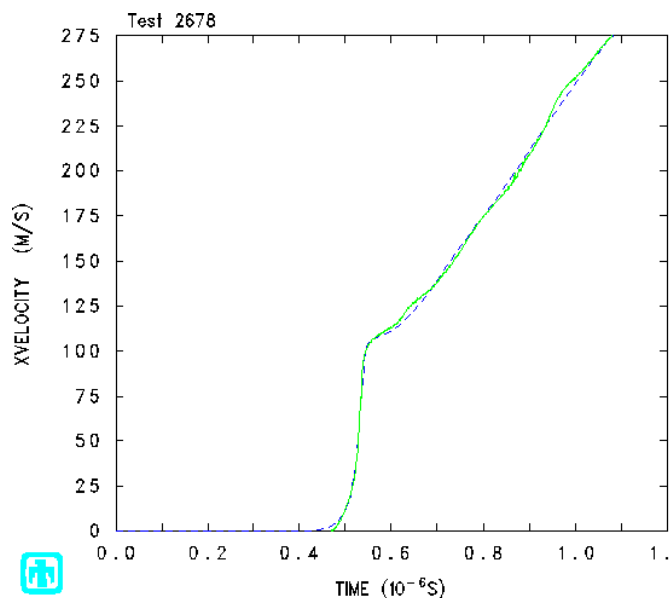
$$\text{pore ratio: } \Psi = \frac{f}{1-f}$$

This analytical work proves that the plastic limit curve should not be used to approximate the yield function in tension. Doing so results in an unphysical energy in the macroscale model. However, using the *envelope* is adequate to avoid negative plastic work.

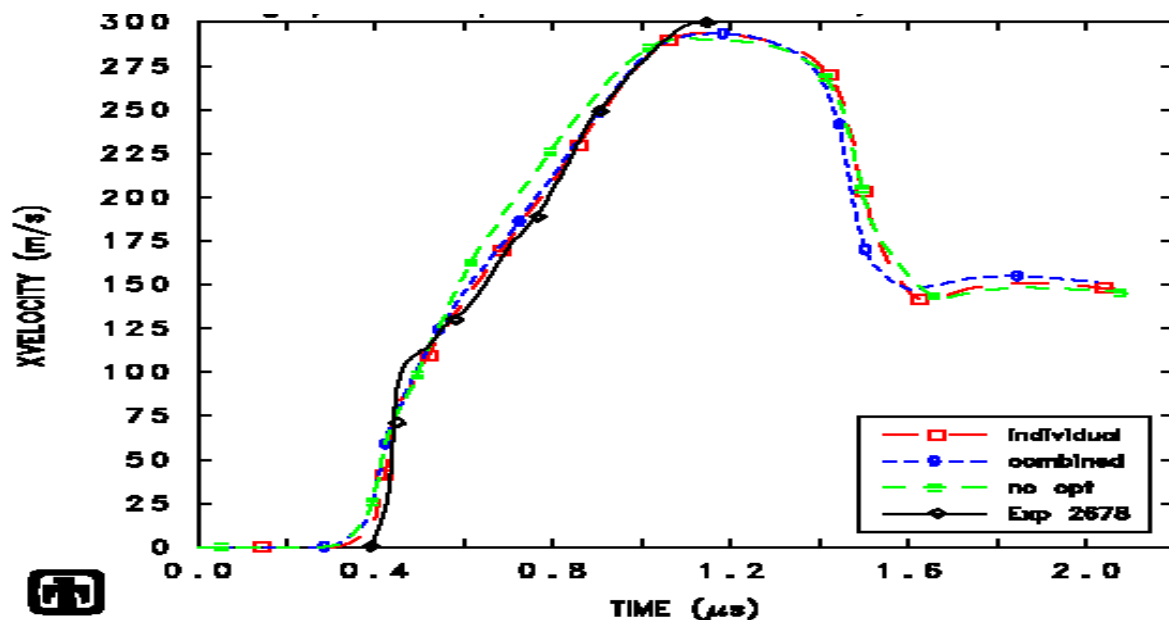


# DAKOTA optimization status

## LAST YEAR



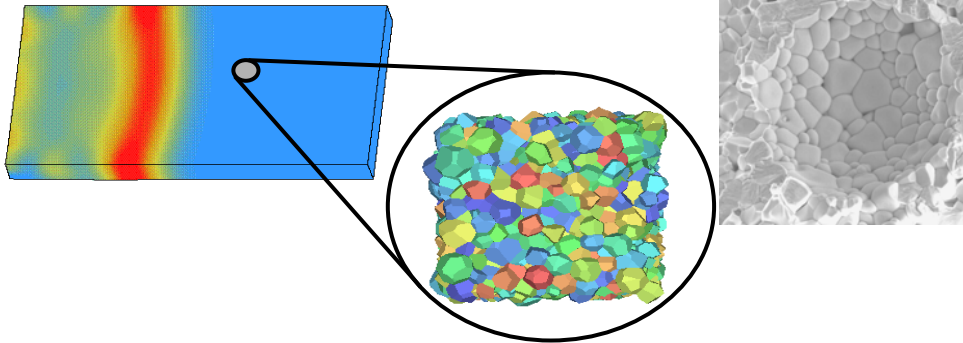
## THIS YEAR



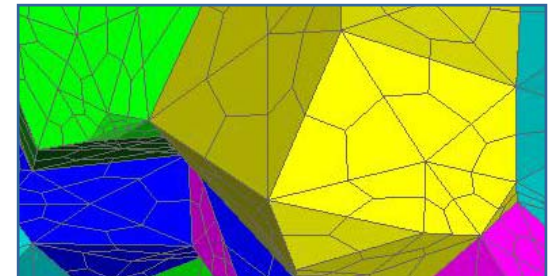
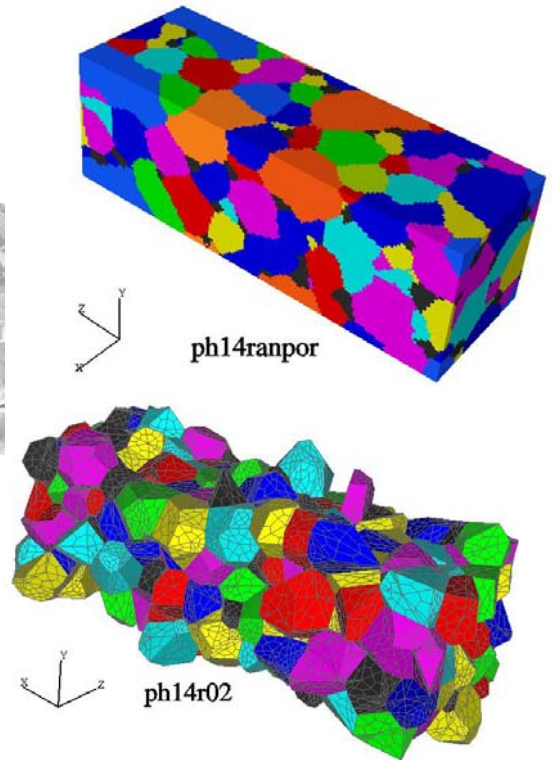
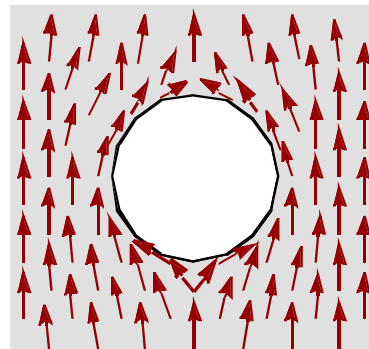
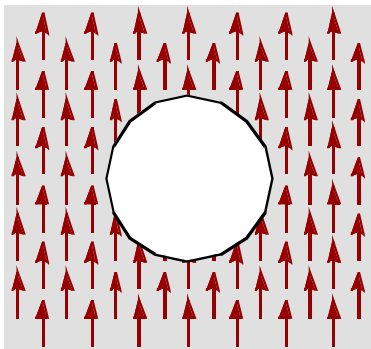
Single-experiment agreement has gone down, but overall test SUITE agreement has improved. DAKOTA optimization has illuminated deficient components in the material model.

# Mesoscale modeling of PZT

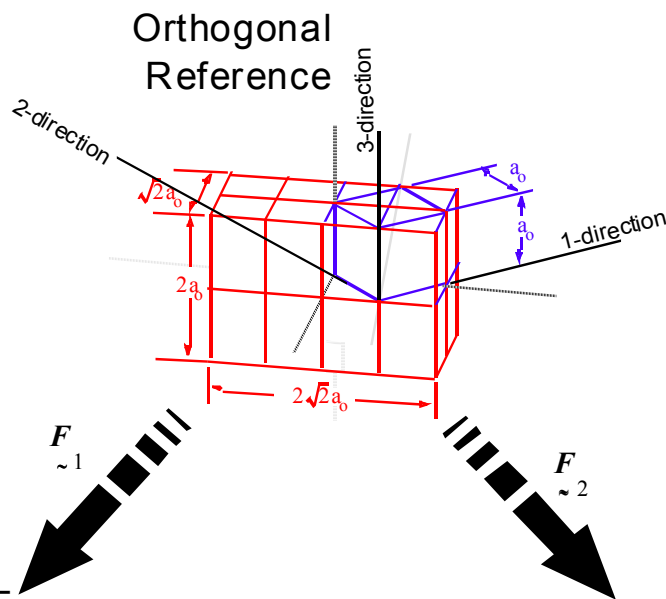
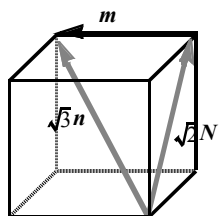
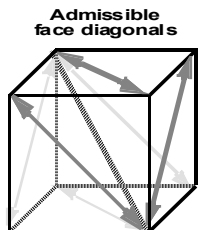
Goal: model shock-induced depoling of PZT at both macro- and meso-scales



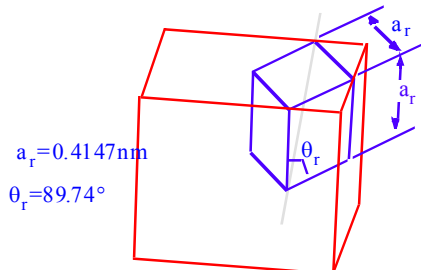
Assign initial occupancies to create a zero divergence field.



# Transformation strain

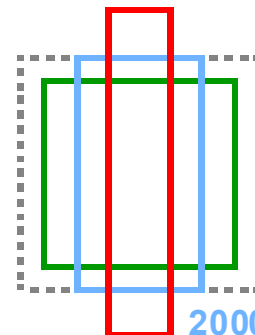
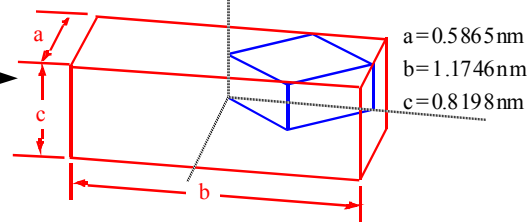


Rhombohedral FE  
(stretch along body diagonal)



$$\tilde{F} = \tilde{F}_2 \cdot \tilde{F}_1^{-1}$$

Orthorhombic AFE  
(stretch along dotted lines)



$$\tilde{\epsilon} = \frac{\epsilon_v}{2T+1} \begin{bmatrix} T & 0 & 0 \\ 0 & T & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Undeformed

1999 (T=1)

2000 (T=0, with distribution)

2001 (-1/2 < T < 0, with distribution)

```
DO I=1,3
DO J=I,3
  F(I,J)= OPALF * FDIAG(I)* FDIAG(J)
$          + OPBET * FDP(I)* FDP(J)
$          + OPGAM * EDGE(I)* EDGE(J)
  F(J,I)=F(I,J)
ENDDO
VEC(I)=F(I,1)*BDIAG(1)+...
DO J=1,3
  F(I,J)=DUM*F(I,J)
$          +COEF*VEC(I)*BDIAG(J)
ENDDO
ENDDO
```



# Mesh-free methods: Motivation

---

## Potential Advantages

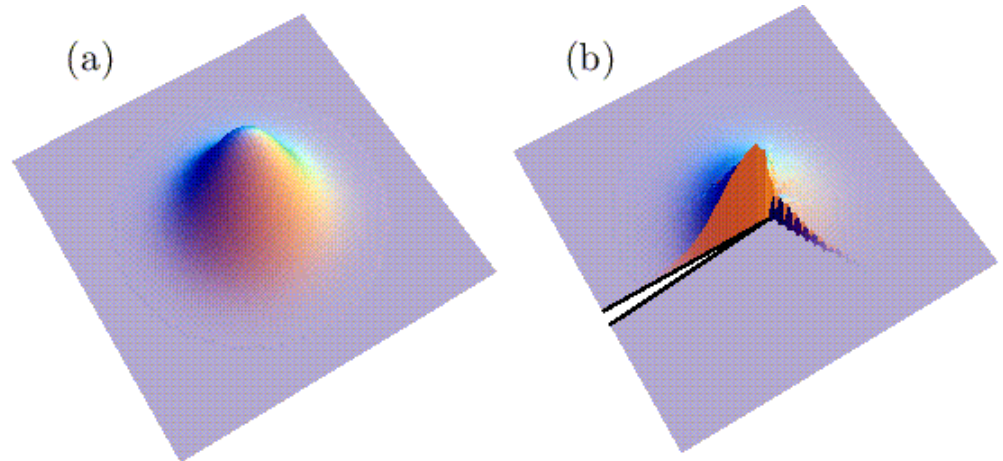
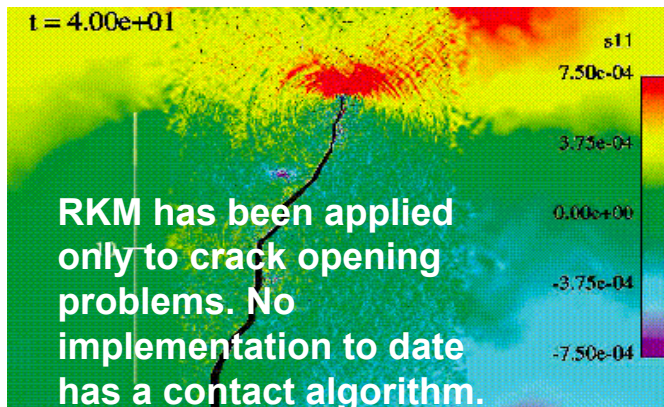
- Better handles large material distortion (no mesh to tangle).
- Lagrangian particles eliminates constitutive advection errors.
- Customized shape functions with desired regularity.
- High rate of convergence.
- Naturally conforming.
- Easy h- and p- adaptivities.

## Pervasive Disadvantages

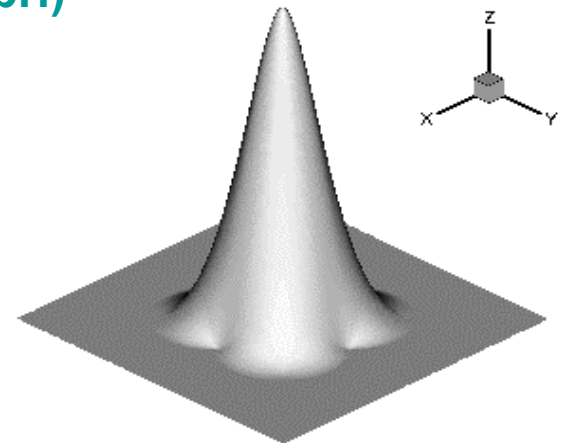
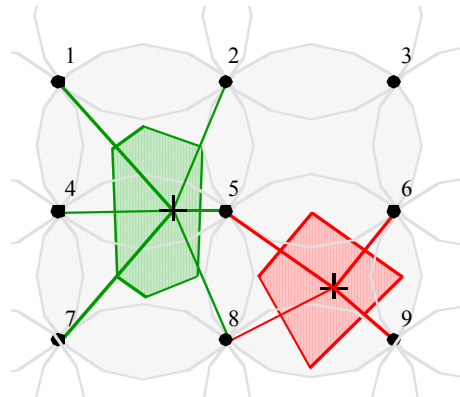
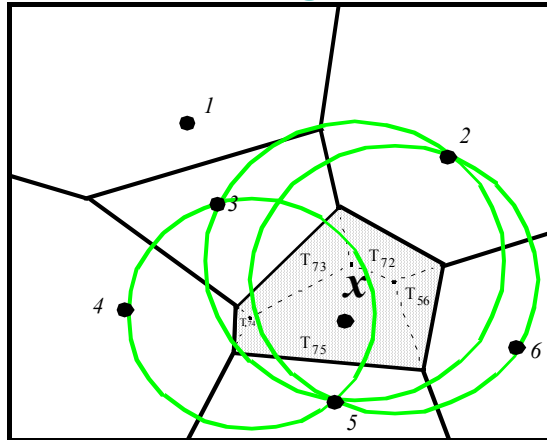
- Complicated boundary treatment.
- Higher-order shape functions require higher order integration rules.
- Particle search is usually needed.
- Boundary detection is required.
- Large bandwidth in stiffness matrix (RK).
- Continuous field approximation is difficult (often non-interpolating).
- Galilean and/or Lagrangian invariance is sometimes violated.
- Finding accurate field gradients is extremely difficult.
- Handling contact and friction is awkward.

# Mesh-Free CONTENDERS

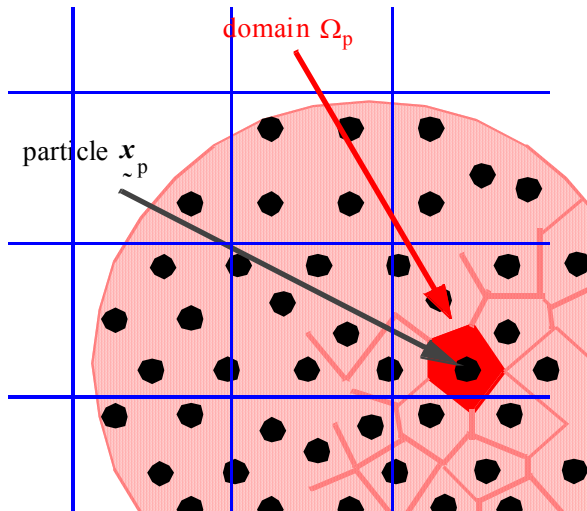
## RKM Sandia-Livermore (Klein, Foulk, Chen, Wimmer, and Gao)



## Natural Neighbor Method, LANL (Crane, Shimbri)



# CONTENDER: The Material Point Method (MPM)



Standard weak formulation applies on the

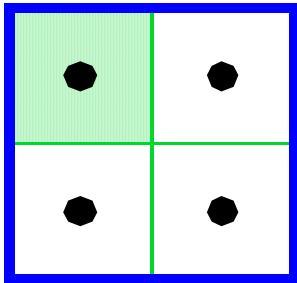
grid:  $\sum_{j=1}^n m_{ij} \mathbf{a}_j(t) = \mathbf{f}_i^{\text{int}}(t) + \mathbf{f}_i^{\text{ext}}(t)$ , where

$$m_{ij} \equiv \int_{\Omega} N_i(\mathbf{x}) N_j(\mathbf{x}) \rho dV, \quad \mathbf{f}_i^{\text{int}}(t) = - \int_{\Omega} \underline{\underline{\sigma}}^s \cdot \underline{\underline{G}}_i(\mathbf{x}) \rho dV,$$

and

$$\mathbf{f}_i^{\text{ext}}(t) = \int_{\partial\Omega_T} \underline{\underline{T}} N_i(\underline{\underline{\eta}}) dS + \int_{\Omega} N_i(\underline{\underline{\eta}}) \underline{\underline{b}} \rho dV.$$

For FEM, Gauss points are used to compute these integrals.



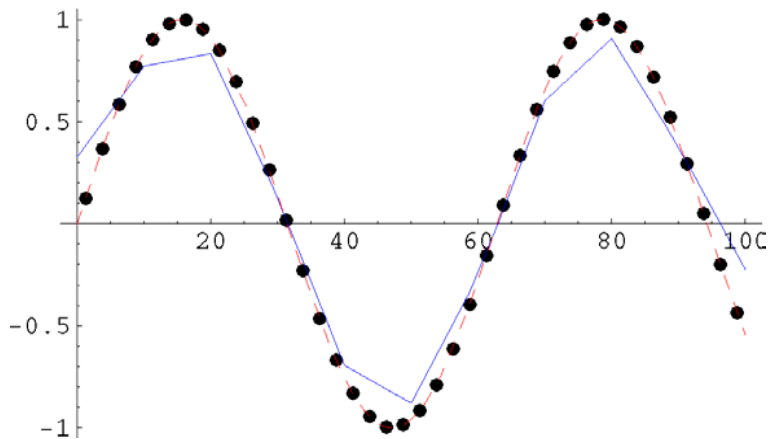
However, for the MPM,

$$\int_{\Omega} f(\underline{\underline{x}}) \rho dV \equiv \sum_{p=1}^N \int_{\Omega_p} f(\underline{\underline{x}}) \rho dV \approx \sum_{p=1}^N f_p M_p$$

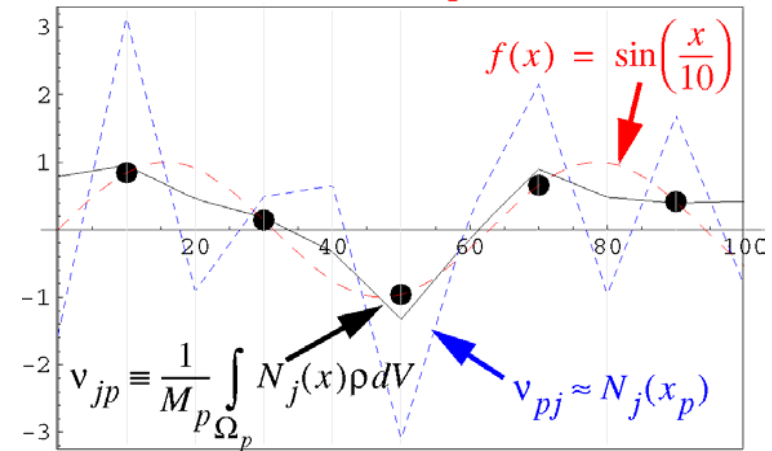


# MPM (implied) particle basis

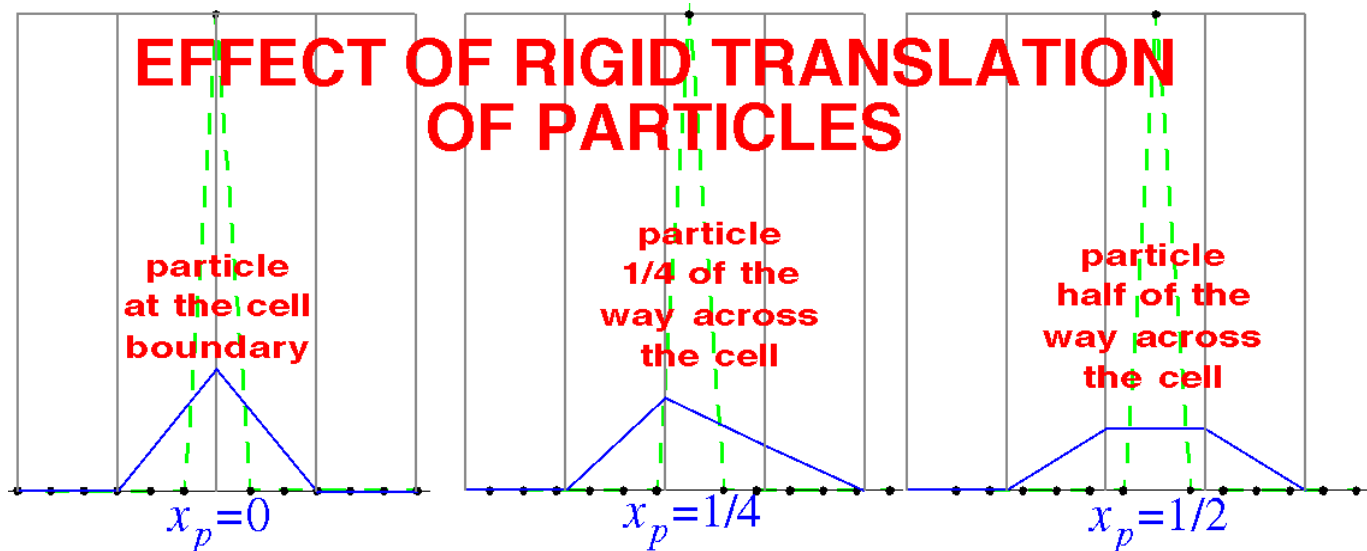
## Effect of lumped mass



## Effect of expansion

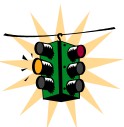
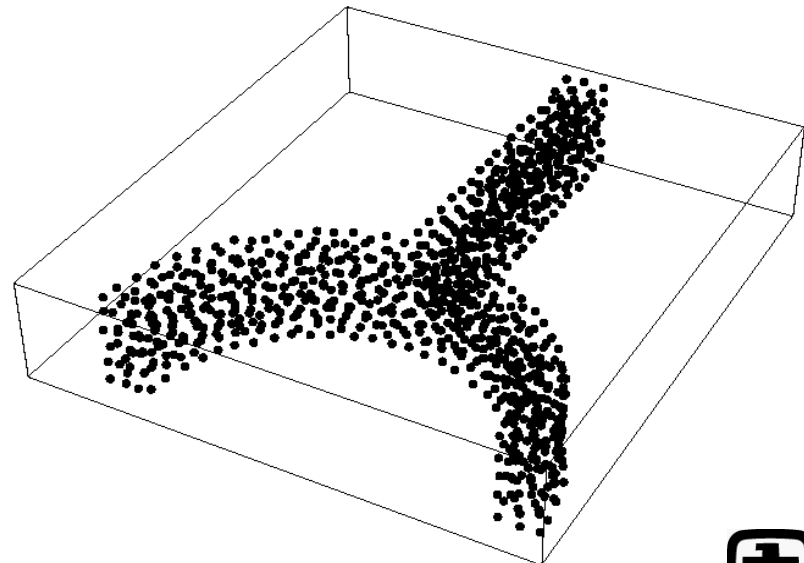
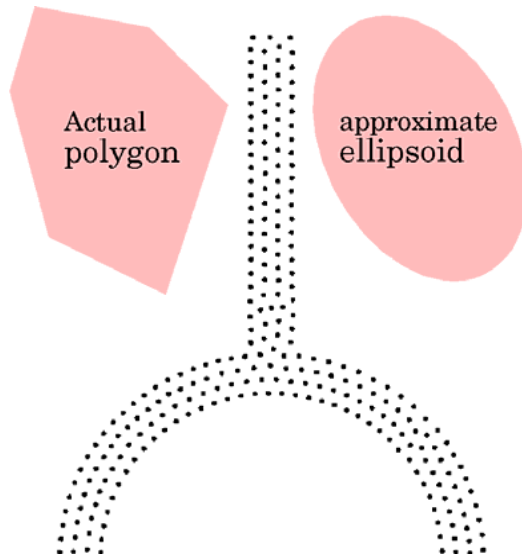
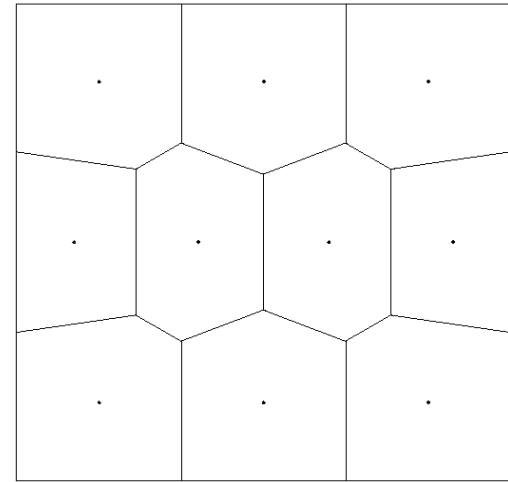
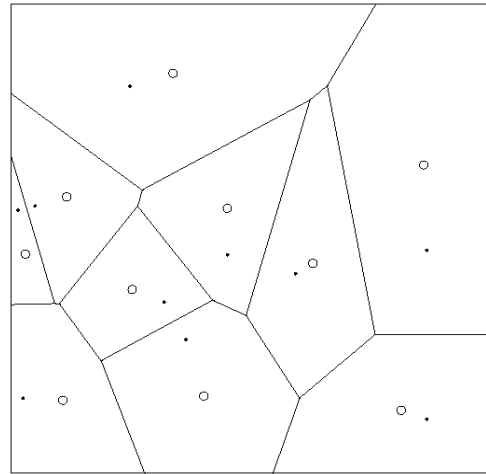
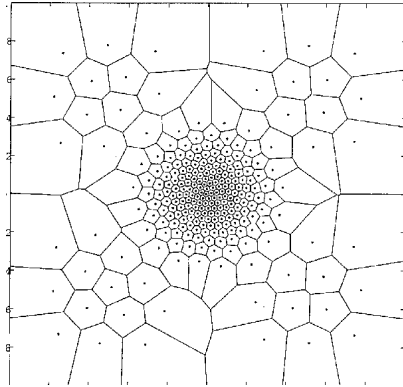


## EFFECT OF RIGID TRANSLATION OF PARTICLES



# Centroidal Voronoi distributions

## Conforming distributions





# In summary, ...

## we are

- 15 professionals with ~270 years of combined experience,

## who work

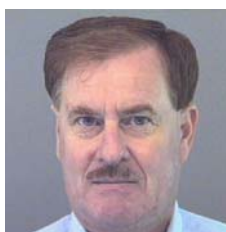
- in the area of shock physics and M&S environments,

## ranging from

- research to development to application to support, and

## funded by

- a large and diverse customer base.



# We are ...



Ray Bell

- BS Physics - University of Arizona  
Graduate work - University of Florida thru Eglin AFB
- Major USAF, ret. (7 years hydrocode dev. and app.)  
11 years @ NMERI/S3 (hydrocode dev. & app.),  
4 years @ SNL (hydrocode dev. & app.)
- 3 kids ranging in age from 13 to 31, and 2 grandkids



Rebecca Brannon

- BS ME - UNM  
MS/PhD Engineering Mechanics - U of Wis., Madison
- 8 years @ SNL (Comp. Physics)
- Likes juggling, watching movies, square dancing, skiing, teaching motorcycle safety, collecting puzzles, and reciting "geeky" poetry, Nintendo fanatic

# We are ...



Pat Chavez

- BS Math & Physics - NM Tech,  
MS Applied Math - RPI,  
PhD Applied Math - Cornell
- 25 years @ SNL (Comp. Physics, CAD/CAM/CAE, TDY/NIST, NWSBU, Comp. Physics)
- Master Gamer ('98 USA finals, '98 World finals hold/officiate tourneys) & Paintballer



Bob Cole

- BS ME - Tulane,  
MS Engineering Mechanics - VPI  
ABD Numerical Methods - Tulane
- 7 years @ US Navy Surface Weapons Center (gun M&S),  
13 years @ Waterways Experimental Station (hydro code),  
7 years @ Private Sector (hydro code dev./app.),  
3 years @ NMERI (WIPP),  
3 years @ SNL (Comp. Physics)
- Met wife at Mardi Gras 33 years ago; still counting after 3 grown children & 2 grandchildren. Cannot run for President, even if I wanted to; the US constitution so states.

# We are ...



## Dave Crawford

- ScB/PhD Physics - Brown
- 8 years @ SNL (Comp. Physics)
- I remember as a kid thinking that I may one day go to the Moon and that by 2000 we would certainly have landed on Mars. Do we really want to be remembered as the generation that saved social security yet our greatest space-based achievement is to build a condominium a mere 200 miles away?



## Paul Demmie

- BS, PhD Physics - Univ. of Pittsburgh, Sandia Certificate of Computer Simulation
- 5 years @ Univ. of Pitts. (Professor of Math & Physics), 7 Years @ EG&G Idaho (Nuclear Reactor Safety), 17 Years @ SNL (NR Safety, BMD, NW Surety, Comp. Phys)
- Plays cello/chamber orchestra and enjoys photography

# We are ...



Millie Elrick

- BS Engineering Physics - Montana State  
MS Physics - Lehigh
- Last 12 years working on CTH
- My first Social Security check arrives in March



Archie Farnsworth

- BS/MS Engineering Science/Mechanics - ASU,  
PhD Engineering - Brown
- 31 years @ SNL (NW Enviro. Testing, Inertial Fusion  
Target Design, Nuclear Weapon Effects, Optical  
Initiation of HE, Optical Signatures)
- Father of 7, grandfather of 9, CLDS Leader (Bishop)

# We are ...



Marlin Kipp

- BS Engineering Mechanics - Lehigh  
MS/PhD Applied Mechanics - Lehigh
- 27 years @ SNL (Comp. Physics - dynamic fracture and fragmentation, reactive models for explosives, NG standoff simulations, explicit simulations with foam, debris clouds, granular explosives, and concrete)
- Bicycle commuter (>50K miles), hiker (likes Colorado 14'er walkups), woodworker (chairs, tables, beds, etc.)



Jason Libersky

- BS Biology - NM Tech,  
BS Astrophysics - UNM,  
BS Religion - UNM
- 5 years as Surgical Assistant/Organ Procurement,  
2 years as Environmental Engineer,  
2 years at SNL (student intern - Comp. Physics)
- Plays cello, loves to cook and write



# We are ...



Marilyn Murray

- 1/2 BA degree in Business
- 20+ years of secretarial experience (UC-Boulder, UW-Madison, NMSU, Rice, UNM in the areas of Criminal Justice, Agronomy, Philosophy, Engineering, NASA Relations, Ecology and Evolutionary Biology, etc)  
5+ years @ SNL (Security, Comp. Physics)
- Blessed to grow up on a farm where I was a typical 4-H kid including raising my horses (Dolly & Darling) and helping with farm chores (planting, harvesting, transporting)



Stewart Silling

- BS NE/Physics - MIT,  
M Eng. NE - Berkeley,  
PhD Applied Mechanics - CalTech
- 3 years @ SAIC (beltway bandit),  
2 years @ NRC (nuclear waste regulator),  
3 years @ Brown University (Professor),  
10 years @ SNL (Comp. Physics)
- Father of twins, cat fancier, and railroad nut

# We are ...



## Paul Taylor

- BS/MS Engineering Mechanics - Penn State  
PhD Theo. & App. Mechanics, University of Illinois
- 20 years @ SNL (Solid State Science - simulation & study of material behavior on atomic length scales, Comp. Physics - constitutive model development, hydrocode development, CTH development lead)
- “Jack” of many pleasures/trades - boating (sail & power), skiing (water & snow), scuba diving, flying, vintage car restoration, home improvement